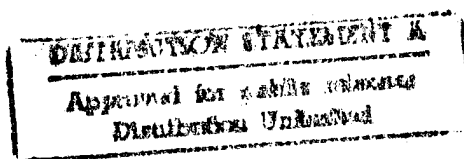




EVALUATION OF FLAWED COMPOSITE STRUCTURAL COMPONENTS UNDER STATIC AND CYCLIC LOADING



BY

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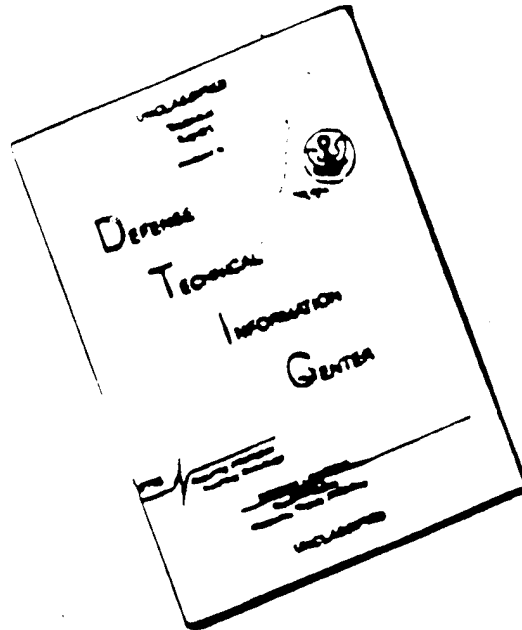
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| 16. Abstract This report presents the results of a program investigating the effects of initial defects on the fatigue and fracture response of composite laminates. The structural laminates investigated were a typical angle ply laminate, a polar/hoop wound pressure vessel laminate, and a typical engine fan blade laminate. Defects investigated were full and half penetration circular holes, full and half penetration slits, and countersink holes. Results are presented showing the effects of the defect size and type on the static fracture strength, fatigue performance, and residual static strength. The results of inspection procedures are shown, describing the effect of cyclic and static loadings on damage propagation in composite laminates. The data in this study were used to define proof test levels as a qualification procedure in composite structure subjected to cyclic loading. | | | | | |
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FOREWORD

This report summarizes the work accomplished on NASA Contract NAS3-19709, "Evaluation of Flawed Composite Structural Components Under Static and Cyclic Loading."

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Performance of this contract was under the direction of the Boeing Military Airplane Development (BMAD) organization of Boeing Aerospace Company. Dr. R. R. June, reporting to Mr. D. E. Strand who heads the Structures/Materials Technology organization, was the Program Leader. Mr. T. R. Porter was the Technical Leader, C. R. Speelman coordinated specimen fabrication, C. C. Kissler provided testing support and L. R. Hause was responsible for ultrasonic inspection support.

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INTRODUCTION

The objective of this program was to derive data for evaluating the integrity of fiber composite components. In particular, the static and cyclic performance of three potential composite laminate designs containing inadvertent flaws and natural defects was investigated. The results address the following topics:

- 1) Effect of defect type and size on static fracture.
- 2) Effect of defect type and size on fatigue.
- 3) Descriptions of the effects of static and cyclic loadings on damage accumulation in material surrounding the various stress concentrations.
- 4) The effect of preloads on damage growth, static strength, and cyclic load behavior.
- 5) The viability of proof loading as a qualification method for advanced composite structure, and the development of approaches to application of proof testing.

Data were obtained on the effects of six different types of stress concentrations or flaws (full and half penetration circular holes, full and half penetration sharp slits, excessive voids, and delaminations) on the static strength and fatigue lives of three different graphite/epoxy composite materials. The test panels were fabricated from T-300/934 0.3 m (12 in) wide prepreg tape. Three different 20-ply laminates were tested. These included a typical angle ply laminate $((0/\pm 45/0/90)_S)_2$, a laminate that is representative of polar/hoop wound pressure vessels $((0_3/\pm 80)_2)_S$, and a laminate that is representative of fan blades for turbine propulsion systems $((0/+30/0^*/-30/0)_2)_S$. The fan blade laminate contains four plies of S-glass (denoted by *) to improve the fracture performance. Both static and cyclic

tests were conducted on specimens containing one of three different sizes of each type of defect. Comparison specimens were preloaded to 90% of their ultimate load capacity, prior to static and cyclic testing, to assess the potential effects of proof loading. Intermittent nondestructive inspection was used to detect changes in defect geometry, and other structural changes occurring in the region immediately surrounding the defects. The test data were evaluated, using current composite fracture and fatigue analysis concepts. The effectiveness of using proof test procedures for quality assurance of composite components was evaluated.

The program was divided into six tasks. Task I defined the materials, layups, fabrication and processing steps, defect fabrication methods, and design and fabrication of test specimens. Tasks II, III, and IV consisted of static, tension/tension, and tension/compression cyclic testing, while Task V included data analysis and Task VI reporting.

The report contains a presentation of the specimen preparation, test procedures, static and cyclic test results, and a potential proof test method. All the test data, ultrasonic inspection data, crack opening displacement data, and photographs of the test specimens are included in the appendices.

SPECIMEN DESIGN AND MANUFACTURE

The test specimen materials, design, and fabrication procedures were selected to permit the generation of data for evaluation of flawed structural components. The components considered were a general purpose laminate structure, a polar/hoop wound pressure vessel, and a turbine engine fan blade.

Materials

The materials used for the program were Thornel T-300 graphite fiber, 901 S-glass fiber, and Fiberite 934 epoxy resin. Intermediate stiffness graphite/epoxy was selected as the basic material for the program, because of its wide usage, moderate cost, and established structural performance. The Thornel T-300 graphite fibers were selected since they can be supplied with a twist making them suitable for general purpose structure as well as filament winding pressure vessels. The fiberite 934 resin system satisfied the requirements of a general purpose epoxy and has a wide range of applications in aerospace structures. In the turbine engine fan blade layup 901 S-glass fiber plies were interspersed with the T-300 fiber plies to improve impact damage resistance of the laminate. This S-glass/graphite hybrid was selected on the basis of prior work (References 1 through 3) demonstrating significantly improved impact damage tolerance.

Layups and Stacking Sequences

Three different layups were used in the fabrication of test specimens, as shown in Figure 1. The first layup (L1) was a 20-ply balanced layup representative of a practical aerospace application. This layup is moderately directional, and would be used to support biaxial loads having about a 2:1 ratio. The second layup (L2) is representative of spacecraft pressure vessels, fabricated using both polar and hoop wraps. The third layup (L3) is representative of turbine fan blades or, possibly, tubular support struts. The S-glass fiber was included as zero degree plies.

The stacking sequence for layup L1 was selected based on symmetry and load transfer requirements. The stacking sequence was $((0/+45/0/90)_S)_2$ and has distributed (0) plies throughout the thickness.

The stacking sequence for layup L2 is representative of a typical pressure vessel layup. There are two basic approaches to polar/hoop wrapping of aerospace pressure vessels. If the hoop thickness is thin, all the polar wraps can be applied at once followed by all the hoop wraps. When the hoop thickness is too large to prevent slippage of the hoop wraps at the end of the cylinder, the polar and hoop wraps are interspersed. This would typically be accomplished by applying one revolution (2 plies) of polar wrap followed by three plies of hoop wrap. The resulting stacking sequence is $(0/0/0/+80/-80)$. Hence, stacking sequence for laminate L2 was $((0/0/0/+80/-80)_2)_S$.

The stacking sequence for layup L3 was representative of those used in composite turbine engine blades. Two possible approaches are the dispersed ply approach and the core-shell approach. The dispersed ply approach was used because such layups are less subject to delamination due to foreign object impact. A representative stacking sequence then becomes $((0/+30/0^*/-30/0)_2)_S$. The asterisks indicate the plies that are replaced with S-glass to increase fracture toughness of the laminate. Replacement of the middle ply results in an even distribution of the hybridizing material throughout the panel.

Test Specimen Configuration

The test specimen configuration is shown in Figure 2. The 76 mm (3.0 in) width was chosen to provide specimens large enough to preclude significant interaction between the stress concentration and stress-free specimen boundaries. The specimen was designed so that the stress concentration factor for the largest defect would be within five percent of the corresponding stress concentration factor for an infinitely wide plate. The test section was selected as twice the specimen width to ensure representative load distribution around the imposed defect. The zero degree laminate direction

corresponds to the axial direction of the specimen. Woven fiberglass grip tabs were bonded to the specimen.

Test Specimen Fabrication and Processing

Specimen fabrication and processing steps are illustrated in Figure 3. Laminates were laid up and cured in 81 cm (32 in) wide panels having lengths ranging up to 244 cm (100 in). Specimens for laminates L2 and L3 were cut from a single panel. Two panels were required for L1 specimens. The fiberglass end tabs were bonded to the basic laminates. Finally, the panels were sawcut into specimen blanks. The panel fabrication steps were as follows:

- 1) Remove material from freezer and allow it to come to room temperature before unwrapping.
- 2) Unwrap material and cut tape to length. Use a template to cut angle plies to size. (Allow excess on all edges.)
- 3) Lay up plies.
- 4) Debulk after 4th, 8th, 12th, 16th, and 20th ply by holding the laminate under vacuum for 15 to 20 minutes.
- 5) Cover laminate with perforated FEP, one ply of 1581 fiberglass bleeder for each four plies of laminate, a layer of nonperforated FEP, a metal caul sheet, two layers of 1581 fiberglass breather, and a vacuum bag.
- 6) Cure laminate in an autoclave using the following cure cycle:
 - o Apply vacuum.
 - o Increase autoclave temperature so that laminate temperature increases at a rate of 0.5 to 2.8°C (1 to 5°F) per minute.

- o Hold 60 min at $(121^{\circ}\text{C} \pm 5.5^{\circ}\text{C})$ ($250^{\circ}\text{F} \pm 20^{\circ}\text{F}$).
 - o Apply 689 kPa (100 psi) pressure 15 minutes after the laminate reaches temperature.
 - o Increase laminate temperature to $177^{\circ}\text{C} \pm 5.5^{\circ}\text{C}$ ($350^{\circ}\text{F} \pm 10^{\circ}\text{F}$) at a rate of 0.5 to 2.8°C (1 to 5°F) per minute.
 - o Hold at temperature for 120 min ± 5 min., then cool under pressure.
- 7) Cut laminate panels to length of test specimens.
 - 8) Lay up fiberglass/epoxy grips on the panel edges.
 - 9) Vacuum bag and cure in an autoclave at 121°C (250°F).
 - 10) Remove panels from autoclave and cut specimens from the panels.

Specimen Defect Geometry

A number of defects can occur in composite laminates due to either manufacturing, handling, or inservice damage. Defects that can be found in the basic laminates are:

- 1) Excessive porosity or voids due to contamination of the prepreg materials, geometrical restrictions that prevent the escape of volatiles during cure, or low curing pressure.
- 2) Wrinkled or nonaligned fibers due to improper layup, thickness changes, etc.
- 3) Resin-rich and resin-starved areas.
- 4) Impacted damaged surface areas, resulting in delaminations or broken fibers.

- 5) Scratched or gouged surfaces caused by mishandling during manufacture or inservice damage.

There are also a number of defects associated with the use of fasteners in composite structure. Some of these are:

- 1) Delaminations near the exit side of drilled holes due to inadequate backing or excessive drill pressure.
- 2) Overly deep countersinks.
- 3) Local damage due to excessive fastener torque.
- 4) Resin starved bearing surfaces, resulting from excessive heat from drilling.
- 5) Relocated holes where mislocated holes have been redrilled.

The potential effects of several of these defects were assessed by testing laminates containing defects simulated by stress concentrations. These defect types can be categorized as (1) sharp defects that break or cut filaments, (2) blunt defects that cut or break filaments, (3) delaminations, and (4) poor resin properties. The defect categories that include cut or broken filaments were represented by holes and sharp slits. Both full penetration (FP) and half penetration (HP) holes and slits were tested, as shown in Figure 4. The delaminations were produced by inducing a disbond into the laminate during cure. In addition to these stress concentrations, potential natural defects typical of the particular laminate application were also tested, as shown in Figure 5.

For laminate L1, specimens were tested that had holes containing overly deep countersinks. Deep countersinks are often unavoidable due to the lack of thickness of laminate skins. This condition was simulated by countersinking holes so that the countersink extended through the laminate thickness and left a sharp edge at the exit side of the hole.

For filament-wound pressure vessels, great care must be taken to provide the correct pressure during cure. Hence, it is appropriate to investigate the effects of low pressure on fracture and fatigue strength of laminate L2. Three variations of curing pressure were used, 345 kPa (50 psi), 172 kPa (25 psi), and 86 kPa (12.5 psi). The normal curing pressure is 689 kPa (100 psi).

For laminate L3, tests were conducted in a 20-ply layup that contained no S-glass. These tests were conducted to allow an evaluation of the effectiveness of the S-glass in increasing the fracture toughness of the laminates.

The hole and slit sizes selected for test were 3.18 mm (0.125 in), 9.52 mm (0.375 in), and 15.87 mm (0.625 in). These sizes cover the range of most practical fastener diameters. They are also at the threshold of detectable damage sizes for many common inspection procedures. The same sizes were used for the surface length of the half penetration defects, since when partial penetration damage exists in structure, the most obvious dimension is the length of the damage on the surface.

The type and size codes used to identify each of the defects are given in Table I.

All slits were perpendicular to the primary load carrying direction of each laminate. This means that they were perpendicular to the zero degree fibers. The zero degree fibers correspond to the hoop direction of a cylindrical filament-wound pressure vessel for laminate L3.

The slits were fabricated by means of ultrasonic machining. Ultrasonic machining is typically used to produce cuts of difficult configuration in nonconductive materials. Circular cutter tips were machined with a thickness of 0.06 inch and a sharp radius. The ultrasonic vibrations of the cutter produce a lapping action in an abrasive slurry that carries away the excess material as the cutter penetrates the part. The slit radius in the composite laminate was typically about 0.127 mm (0.005 in) with a smooth surface.

Figure 6 shows a typical partial penetration flaw that has been sectioned to illustrate the root geometry.

The full penetration circular holes were drilled, and the half penetration circular holes were end milled.

TEST PROCEDURES

The test program had the following objectives for each layup and defect:

- 1) Evaluate the initial static strength.
- 2) Establish maximum cyclic stresses for given cyclic lives.
- 3) Monitor the residual static tensile strength during cyclic loading.
- 4) Evaluate the effects of proof loading on cyclic and static behavior.

These objectives were satisfied by following the test load sequences shown in Figure 7. The numbers of test specimens and test conditions are defined in Tables II, III, and IV.

The first specimen in each series was static loaded to failure. The second specimen was preloaded to 90% of the failure load, unloaded, and then residual static loaded to failure. The remaining specimens were cyclic tested.

However, one-half of these remaining specimens were statically preloaded to 90% of the first specimen failure load prior to cyclic test.

The cyclic testing included specimens that were "fatigue to failure" tests and "fatigue/residual static" tests. The maximum fatigue load was limited in most cases to 90% of the static preload (81% of the estimated static strength). This was established as an upper limit for use in structural applications. The cyclic loading in each test was limited to a maximum predetermined number, as defined in Tables III and IV. In the cyclic tests where failure did not occur after 10^3 , 10^5 , or 1.5×10^6 cycles as appropriate, the specimens were loaded to failure to obtain the residual static strength.

In this manner, fatigue life data were defined for stress levels up to 81% of the static strength, and cyclic lives to 1.5×10^6 cycles. For test specimen configurations that had fatigue behavior that exceeded these conditions (i.e., no fatigue failures at 81% of static strength and 1.5×10^6 cycles), these conditions were considered to be the minimum

performance. However, this minimum fatigue performance would exceed nearly all practical requirements.

Both the baseline static and the residual static test specimens were loaded to failure, using a loading rate of about 1100 N/s. This loading rate resulted in failure in about one minute after the onset of loading. This loading rate was also used for applying the preload.

The majority of the cyclic testing was performed using tension/tension loading ($R = 0.05$). Comparison cyclic testing was performed on laminate L1 test specimens with tension/compression loading. Two cyclic stress ratio values of $R = -1.0$ and $R = -0.5$ were included in these tests. The compression loaded test specimens were supported with two plates covering the specimen faces between the grips. The face plates were constructed of 13 mm (0.5 in) aluminum and faced with Teflon to minimize surface friction. The plates were clamped to the specimen using finger-tight bolts at the plate edge. A 51 mm (2.0 in) diameter central cutout in both plates was placed over the defect for instrumentation and inspection access, and to allow out of plane displacements around the defect. The edges of the specimen were fully supported since the specimen width is greater than the hole size. The 51 mm (2.0 in) diameter circular portion of the test specimen would be stable for panel buckling.

All flawed specimens were continuously instrumented throughout each test to detect both the time, at which and the manner in which, structural changes occur in the region immediately surrounding the defect. This was accomplished by continuous monitoring of the displacement across the stress concentrations using clip gages. Clip gages were spring-loaded against knife edges bonded to the specimen surface at the specimen centerline. For all but the 5/8 FP holes, the knife edges were located immediately above and below the stress concentration, as illustrated in Figure 8. For the test specimens containing the largest full penetration holes, knife edged supports were placed against the hole surfaces. In static tests, both clip gage and load cell were connected to an X-Y recorder to produce a recording of load versus clip gage

displacement. In the cyclic tests, the clip gage was connected to a strip chart recorder to obtain a recording of deflection amplitude versus cycles.

The fatigue test specimens were cycled at a maximum frequency of 10 Hz. The cyclic frequency was reduced to 1 Hz for the first cycles, and again when reading the instrumentation.

The tests were performed in room temperature laboratory air. These ambient conditions were nominally 20°C (70°F) and 40% relative humidity.

STATIC FRACTURE TEST BEHAVIOR

The static testing is discussed in this section. All test data are tabulated in Appendix A of this report. Figures 9 through 14 present static failure stresses and residual static stresses, after preloading, for all the test laminates and defect types.

The results for the half penetration slit tests show less effect of slit surface length on strength degradation. A comparison between the static (NPL) and residual static after preload (PL) specimens can also be made from these figures. The residual static results for the laminate L1 specimens show a slight increase over the NPL specimens. This trend was not consistent with the L2 and L3 laminate specimen results. In all three laminates, a hole and a slit of equal transverse size had essentially the same effect on static strength. It can also be seen from the results shown in Figure 9 that the full depth countersink hole has a strength that corresponds to a hole size equal to the average diameter.

The low cure pressures used in laminate L2 static specimens did not have an effect on static strength. This result is consistent with the conclusion that the static tension properties are fiber dominated in these layups, and are not influenced by the changes in matrix properties associated with the low curing pressures investigated. These data do not support the need for tight control of cure pressures in pressure vessels.

A comparison of the fracture stress of laminate L3 panels for the S-glass hybrid and the all-graphite layups is given in Figure 14. These results show an improvement in fracture stress for the hybrid laminate.

Examination of the failure faces and crack opening displacement (COD) records reveals a difference in the fracture behavior of the three laminates. Sample crack opening displacement records from testing of each of the three laminates with a full penetration hole are shown in Figures 15, 16, and 17. All the crack opening data records are included in Appendix C. The tests for one

specimen configuration are included on one figure. The first recording in each figure is from the static fracture test, followed by the preload record, the residual static fracture record, and the preloaded fatigue specimen records. Laminate L1 had nearly a linear COD record to failure as shown in Figure 15. In some cases there is an indication of damage growth just prior to failure that is are manifested by sudden small increases in the crack opening. Laminate L1 failure faces showed transverse fracture with a relatively small amount of delamination. Laminate L2 (Figure 16) demonstrated a nonlinear load-COD relationship with an indication of some specimens having a larger amount of sudden damage growth prior to failure. The fracture face of laminate L2 specimens displayed delamination and splitting. The delaminations occur in the plane of ± 80 degree plies. The load-COD records for laminate L3 specimens (Figure 17) were initially linear, with sudden occurrences of damage growth prior to maximum load. There was a sudden drop in maximum load when the graphite fibers failed in the test panel. The test panel had not separated into two pieces, because all the glass fibers had not failed. There was extensive damage to the panel, however, in the form of fractures and delamination. Continued loading of the panel resulted in separation of the panel at a much lower load than that which caused the initial fracture of the graphite fibers. The failed test specimen has extensive delamination in the planes of the S-glass. Final separation of the panel resulted in fiber pull-out of the S-glass giving a "broom like" appearance. The COD records obtained during preloading of the fatigue specimens of each of the laminates followed the trends for the static fracture specimens. The linear behavior of the L1 laminates resulted in a single load/unload curve. The COD records show that laminates L2 and L3 experienced damage around the stress concentration due to the application of the preload.

The static data developed for the three laminates were examined for a consistent trend between failure stress and defect size. Figure 18 presents the static data for the full penetration holes and slits, as a function of defect size. As a comparison in this figure, the inherent flaw analysis prepared by Waddoups, et al (Reference 4), was applied to the data. In this analysis, an inherent flaw is assumed to control the static strength of the

undamaged laminate, and is assumed to exist at the edge of holes and slits. This condition results in the following expressions for fracture toughness parameters.

For slits (through center cracks)

$$K_C = \sigma_c [\pi (a+a_0)]^{\frac{1}{2}}$$

For holes

$$K_C = \sigma_c [\pi a_0]^{\frac{1}{2}} F(a_0/R)$$

For static unnotched strength

$$K_C = \sigma_c [\pi a_0]^{\frac{1}{2}}$$

where:

- a_0 = inherent flaw size
- σ_c = fracture stress
- K_C = critical stress intensity factor
- a = one-half slit length (for through center cracks)
- R = hole radius
- $F()$ = Bowie function for cracks emanating from a hole

In preparing the curves presented in Figure 18, the data for the unnotched tests and the 15.8 mm (0.625 in) slits were utilized to evaluate the two dependent quantities a and K . As shown in the figure, constant values of the a and K provide trends that are quite good for laminates L1 and L3. For L2, the smallest damage size is more severe than predicted. Also, the inherent flaw size computed for laminate L2 is much larger than for other laminates. Similar analyses are presented in Figure 19 for the average stress failure criteria, and in Figure 20 for the point stress criteria. As shown, the three fracture prediction methods yield comparable results.

CYCLIC LOAD BEHAVIOR

Figures 21 through 52 present the tension/tension cyclic test data for the three laminates. The figures present the applied gross area stress as a function of the number of applied load cycles. Triangle symbols represent static fracture tests, and circles represent cyclic tests. The closed symbols indicate specimens that have been previously preloaded (PL). An arrow indicates a cyclic test that did not result in a fatigue failure.

A review of the data confirms the high resistance of all the laminates to tension/tension fatigue, which is characteristic of such composite laminates. Only the laminates L2 and L3, containing half penetration defects or no defect had a consistent tendency to develop fatigue failures in less than 1.5×10^6 cycles. This is illustrated by the data in Figures 40, 42, and 49 through 52. In the remaining cases, the majority of the cyclic tests were terminated at the targeted number of cycles.

A beneficial effect of preload was noted for the residual static fracture test for laminate L1. The application of a preload to a laminate L1 specimen resulted in a subsequent increase in the preloaded specimen residual static strength when compared to the nonpreloaded static test result. However, the fatigue data do not show such an effect from preloading.

Results of the laminate L1 tension/compression fatigue tests are presented in Figures 53 through 62. The data are presented as applied load cycles against the maximum tension load. Two tension/compression stress ratios R ($R = \text{min load}/\text{max load}$) were tested, (1) fully reversed, $R = -1$ and (2) $R = -0.5$. All test specimens were the general purpose 20-ply laminate L1. This laminate is T-300/934 graphite/epoxy with a $((0/\pm 45/0/90)_S)_2$ stacking. On the figures, the circles represent the $R = -1.0$ fatigue data, the squares represent the $R = -0.5$ fatigue data, and the triangles represent the residual static tests of the specimens that did not fail during cycling. The closed symbols represent test specimens that had been preloaded (PL) to 90% of the estimated static strength prior to cyclic test.

In general, the test data indicate a significant influence of the compression loading on cyclic life. This was in contrast to the small effect found for the tension loads.

When comparing the effects of the various types of defects, it was noted that increasing the notch severity had a greater effect on static than on the fatigue properties. This is illustrated by the relative fatigue performance comparison between the specimens containing holes and the unnotched specimens presented in Figure 63. As shown, the relative fatigue strength of the notched specimens is greater than that of the unnotched specimens.

The test results of disbond defects developed in this program were found to be no different than for unnotched specimens, as illustrated in Figure 64.

A visual comparison of the test specimens after cyclic loadings illustrated the effect of layup on damage propagation. The test specimens constructed from laminate L1, $((0/+45/0/90)_S)_2$, showed only minimal or no visual damage. The appearance of damage was evidenced by a fine craze or split running parallel to the loading direction of the outer 0° plies. Laminate L2 $((0_3/+80)_2)_S$ generally displayed greater splitting than found in laminate L1. The splits in laminate L2 penetrated the outer plies, and were up to several centimeters in length. An example of splitting in laminate L2 is shown in Figure 65 for a fatigue specimen with only 1,000 cycles. A photograph of a similar specimen from laminate L3 $((0/+30/0/-30/0)_2)_S$ in Figure 66 showed only minimal damage. Visual examinations of laminate L1 specimens displayed even less damage. It was concluded that the cyclic fatigue characteristics are influenced by the clustering or dispersion of the (0) plies in the laminate.

These visual observations were extended by the use of ultrasonic records. These records are traces of through transmission scans of the test specimens made with a Holosonics Model 200 unit. Both signal attenuation and a time gate were used, resulting in light areas for delaminations as well as for the edges and initial defects. The inspection records from a half penetration hole are presented in Figure 67. In this case delamination occurs, and is

shown to extend from the defect in a direction parallel to the loading, with the greatest extent of delamination progressing along the center line of the panel. A similar record for a full penetration hole is shown in Figure 68. As shown in this figure, there is no apparent damage extension from the defect, even though the number of load cycles applied is much greater. Records for a full penetration hole specimen from laminate L2 $((0_3/+80)_2)_S$ are shown in Figure 69. The extent of delamination was greater for laminate L2 specimens than for L1.

Similar results were found for the tension/compression test data. Several examples are shown in Figures 70 and 71. Results for a half penetration slit are shown in Figure 70. For this type of defect, the damage propagates above and below the initial slit. The development of edge delaminations can also be seen in this specimen. The edge delaminations developed in specimens with small or no initial defects that were cycled at relatively high stress levels. Figure 71 presents the records for a specimen containing a half penetration hole where the delaminations above and below the defect can be seen. The delamination in this specimen was the result of only 1,000 fatigue cycles.

Appendix B of this report contains all the ultrasonic C-scan records. These records were made for a range of defect types and loading conditions.

The damage growth during cyclic loading was also monitored, using a crack opening displacement gage that was recorded during the cyclic test. These results from the cyclic testing identified the time of damage growth during the testing. Appendix D contains the results of these measurements.

PROOF TEST PROCEDURES FOR COMPOSITE STRUCTURE

The development of data for establishing proof loading techniques for composite structure was a major objective of this program. For illustration, typical requirements for proof loading are shown in Figure 72. A key element is whether the initial strength and the cyclic life or residual strength distribution are controlled in the same manner by an initial defect; i.e., is there a relationship between initial static strength and the fatigue performance.

A second requirement is that the application of the proof load either (1) does not have a detrimental effect on the subsequent structural performance, or (2) the effects on the fatigue behavior can be accurately assessed. The application of the preload had a beneficial effect on only the laminate L1 static test behavior. All other comparisons including the fatigue and the residual static strength after cyclic loading, did not reveal any difference between preloaded and non-preloaded test specimens. Therefore, the application of a proof load was not considered to affect the subsequent performance of the structure.

As a first step in the development of a proof test method, the cyclic test data developed for each flaw type were reviewed to determine the minimum cyclic life associated with given cyclic stress levels. It was recognized that the number of test data points developed for each specimen configuration was limited (six to eight specimens). However, there is a systematic variation in defect type and size in the test program. For this reason, the collective data demonstrate the consistent trend of a sharp transition between stress levels that produce early fatigue failures, and stress levels below which no failures occur. Because of this result, it is possible to construct, from the available data base, S/N curves that represent the maximum allowed cyclic stress for given cyclic lives. Since the maximum demonstrated cyclic stress was used when constructing the curves, further testing could result in higher allowable cyclic stresses. However, because of the curve shape and the

relatively high cyclic stress test results, there could be only a slight increase in the result.

As the next step in the evaluation of proof loading methods, potential relationships between initial static strength and cyclic behavior were investigated. The quantitative evaluation of such a potential relationship is an integral part of developing a useful proof test method. A number of techniques have been proposed (Reference 6 for example), using analytical models. Some were extensions of metallic fracture analysis procedures. Because of the large flaw type and flaw size data base developed in this program, a direct experimental approach was used. As a step in this approach the minimum cyclic data (S/N) curves found for each of the defects were defined. The initial static strength found for test specimens that contained the same defect geometry was used to identify the curves. As illustrated in Figure 73 for the laminate L1 data, these curves present a systematic relationship between fatigue performance and the initial static strength for all types of defects tested. This result is amplified in Figure 74 which defines the cyclic stress level for the selected cyclic lives of 1, 10^2 , 10^4 , and 10^6 as a function of the initial static strength.

Since a relationship exists between initial static strength and fatigue behavior, these curves then define the proof loading requirements to meet defined life and operating stress levels.

Similar analyses were performed for laminates L2 and L3. The results were normalized (to the undamaged static strength) for all laminates at 10^6 cycles, and are presented in Figure 75. As can be seen, laminates L1 and L3 display nearly identical behavior, while laminate L2 shows a slightly different response. However, the variation between all three is only slight, indicating that this result is applicable to a wide variety of composite laminates.

CONCLUSIONS

Three composite 20-ply laminates representative of general structure, pressure vessels and turbo engine fan blades were studied to develop data on their static and fatigue behavior. The test results presented apply specifically to the laminates and test conditions evaluated. However the trends define general behavior for a wide range of laminate configurations. Some general conclusions that are discussed in detail in the report are presented below:

- 1) Initial defects of the type that cut filaments can significantly reduce the static tension strength of composite structure.
- 2) Graphite fiber composite materials are relatively insensitive to tension/tension fatigue, and may be cycled at high percentages of their static strength. In tension/compression fatigue, however, these composite materials exhibit increased sensitivity.
- 3) Half penetration defects are less severe than full penetration defects with the same surface length.
- 4) There is little difference between the performance of laminates with circular holes or with sharp slits in the sizes tested.
- 5) For a wide range of flaw types, there is a relationship between initial static strength and cyclic life. This relationship was found for the three laminates tested, and was used to develop proof load requirements for the types of composites tested. It is expected that this approach will be applicable to other graphite fiber composites as well.
- 6) No detrimental effect on the subsequent fatigue or static strength was found as a result of the application of a proof load.

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Table 1. Defect Type and Size Code

| Defect type \ Approximate diameter or surface length mm (in) | 3.18 (0.125) | 9.52 (0.375) | 15.9 (0.625) |
|--|--------------|--------------|--------------|
| Full-penetration hole | 1/8 FP hole | 3/8 FP hole | 5/8 FP hole |
| Half-penetration hole | 1/8 HP hole | 3/8 HP hole | 5/8 HP hole |
| Full-penetration slit | 1/8 FP slit | 3/8 FP slit | 5/8 FP slit |
| Half-penetration slit | 1/8 HP slit | 3/8 HP slit | 5/8 HP slit |
| 100-degree full-depth countersink hole | 1/8 CSK hole | 3/8 CSK hole | 5/8 CSK hole |
| Circular disbond defect between 15th and 16th plies | — | — | 5/8 disbond |

Table 2. Static Test Matrix

| Laminate | Proof load (% σ_{ult}) | Number of tests | | | | | | | | | | | | | | | |
|----------------|--------------------------------|--------------------|----------------|----|----------------|----|----------------|----|----------------|----|----------------|----|----------------|----|-----------------|----|----------------|
| | | Unflawed Specimens | Circular holes | | | | | | Sharp slits | | | | | | Natural defects | | |
| | | | S ₁ | | S ₂ | | S ₃ | | S ₁ | | S ₂ | | S ₃ | | | | |
| | | | FP | HP | FP | HP | FP | HP | FP | HP | FP | HP | FP | HP | FP | HP | S ₁ |
| L ₁ | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 90 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| L ₂ | 0 | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 90 | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| L ₃ | 0 | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 90 | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

S₁, S₂, S₃ depict defect sizes

FP = full penetration of thickness

HP = half penetration of thickness

Table 3. Tension/Tension Load Test Matrix

| Laminate | Proof load (% σ_{ult}) | Cyclic stress | Number of tests | | | | | | | | | | | | | | | |
|----------------|--------------------------------|---------------|-----------------|----------------|----|----------------|----|----------------|----|----------------|----|----------------|----|----------------|----|-----------------|----|----------------|
| | | | Unflawed | Circular holes | | | | | | Sharp slits | | | | | | Natural defects | | |
| | | | | S ₁ | | S ₂ | | S ₃ | | S ₁ | | S ₂ | | S ₃ | | | | |
| | | | | FP | HP | FP | HP | FP | HP | FP | HP | FP | HP | FP | HP | FP | HP | S ₁ |
| L ₁ | 0 | σ_1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | | 1 |
| | | σ_2 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | | 1 |
| | | σ_3 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | | 1 |
| | 90 | σ_1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | | 1 |
| | | σ_2 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | | 1 |
| | | σ_3 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | | 1 |
| L ₂ | 0 | σ_1 | 1 | 1 | | | 1 | | 1 | 1 | | | 1 | 1 | 1 | | 1 | |
| | | σ_3 | 1 | 1 | | | 1 | | 1 | 1 | | | 1 | 1 | 1 | | 1 | |
| | 90 | σ_1 | 1 | 1 | | | 1 | | 1 | 1 | | | 1 | 1 | 1 | | 1 | |
| | | σ_3 | 1 | 1 | | | 1 | | 1 | 1 | | | 1 | 1 | 1 | | 1 | |
| L ₃ | 0 | σ_1 | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| | | σ_3 | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| | 90 | σ_1 | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| | | σ_3 | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | | |

$\sigma_1, \sigma_2, \sigma_3$ = stress levels corresponding to cyclic lives of 500, 50,000, and 10^6 cycles, respectively

S₁, S₂, S₃ depict different defect sizes

FP = full penetration HP = half penetration

Table 4. Tension/Compression Cyclic Load Test Matrix

| Laminate | Proof load (5 UH) | Cyclic stress | Number of tests | | | | | | | | | | | | | | | | | | | |
|----------------|-------------------|----------------|-----------------|------|----------------|------|----------------|------|----------------|------|----------------|------|----------------|------|--------------------|----------------|----------------|------|----------------|-----------------|--|--|
| | | | Unflawed | | Circular holes | | | | Sharp slits | | | | | | Counter-sink holes | Disbond defect | | | | | | |
| | | | | | S ₁ | | S ₃ | | S ₃ | | S ₁ | | S ₁ | | S ₃ | | S ₃ | | S ₃ | 5/8-in circular | | |
| | | | | | FP | HP | FP | HP | FP | HP | FP | HP | FP | HP | FP | HP | FP | | | | | |
| R | R | R | R | R | R | R | R | R | R | R | R | R | R | R | R | R | R | R | R | | | |
| -0.5 | -1.0 | -1.0 | -0.5 | -1.0 | -0.5 | -1.0 | -1.0 | -1.0 | -0.5 | -1.0 | -0.5 | -1.0 | -0.5 | -1.0 | -1.0 | -0.5 | -1.0 | +0.1 | | | | |
| L ₁ | 0 | σ ₁ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| | | σ ₃ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| | 90 | σ ₁ | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | | | |

σ_1, σ_3 = stress levels corresponding to cyclic lives of 500 and 10^6 cycles, respectively.

S₁, S₃ depict different defect sizes

FP = full penetration HP = half penetration

| DESIGNATION | MATERIAL | LAYUP | APPLICATION |
|-------------|-------------------------------------|---------------------------|---|
| L1 | THORNEL 300/FIBERITE 934 (T300/934) | $[(0/\pm 45/0/90)_3]_2$ | GENERAL STRUCTURE |
| L2 | T300/934 | $[(0_3/\pm 80)_2]_S$ | PRESSURE VESSELS |
| L3 | T300/934 with 901-S | $[(0/+30/0^*/-30/0)_2]_S$ | TURBINE ENGINE FAN BLADES OR SUPPORT STRUTS |

* PLIES THAT ARE REPLACED WITH S-glass

Figure 1. Structural Laminates Evaluated

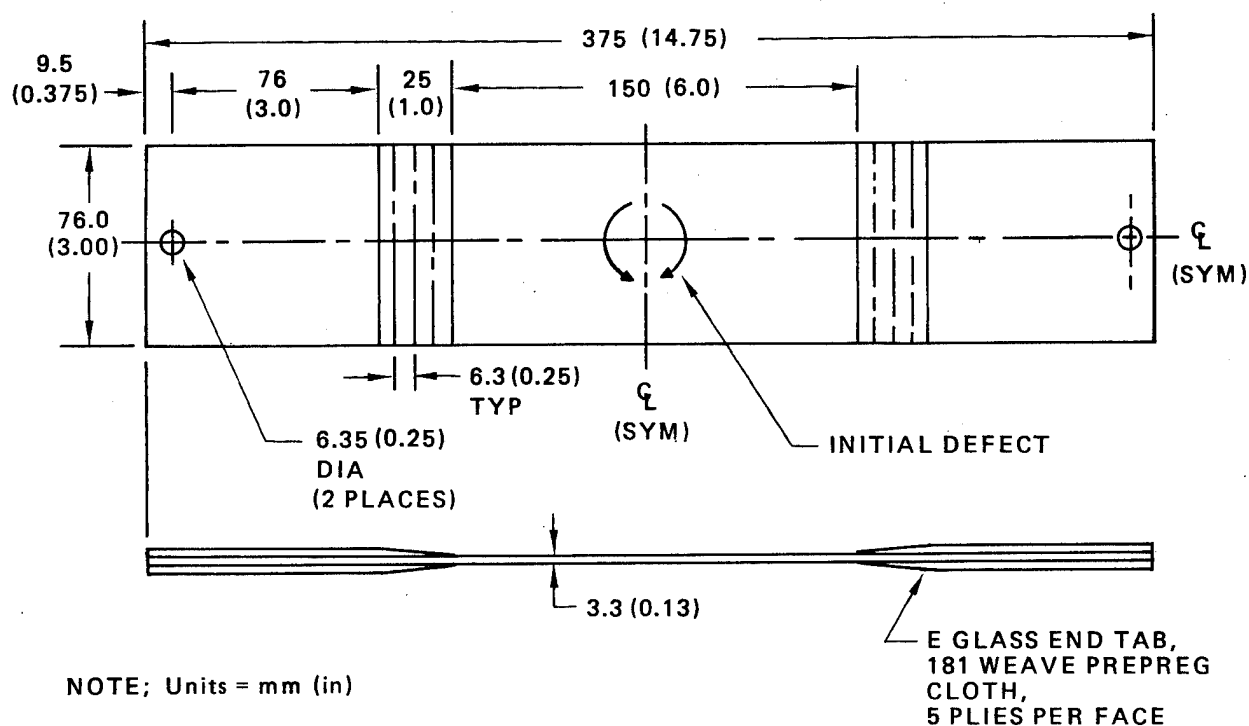
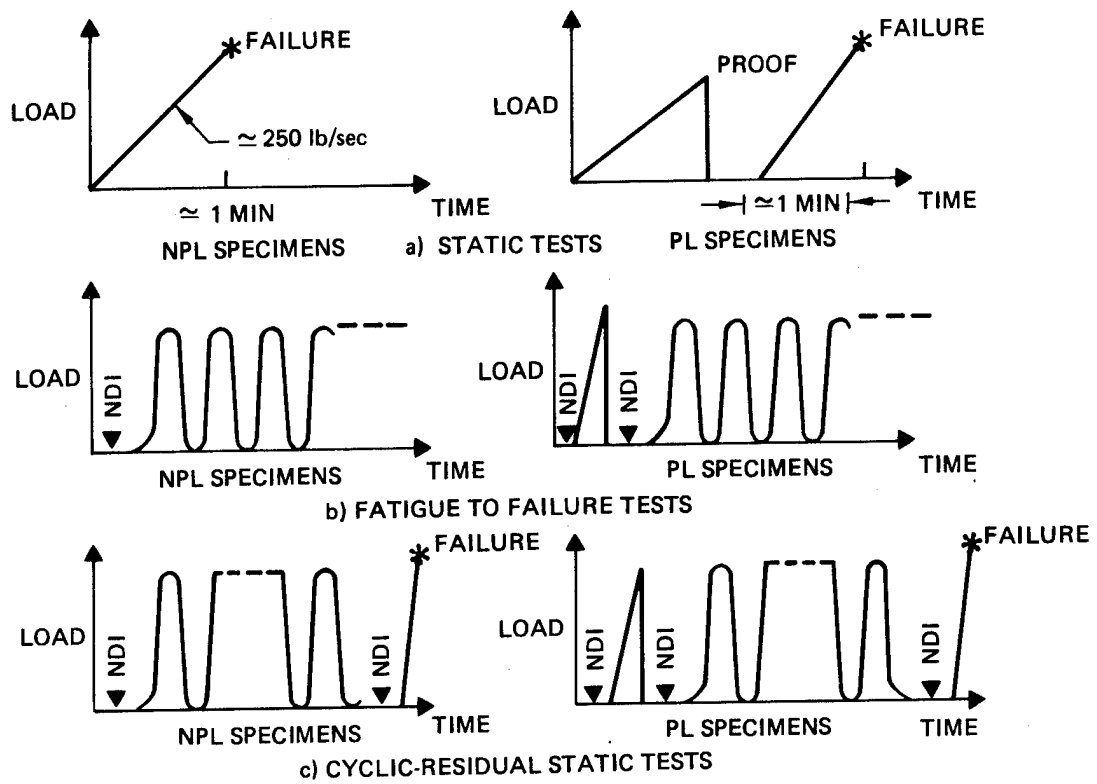


Figure 2. Test Specimen Configuration



NDI = NONDESTRUCTIVE INSPECTION NPL = NON-PROOF-LOADED PL = PROOF-LOADED

Figure 3. Test Program Load Sequences

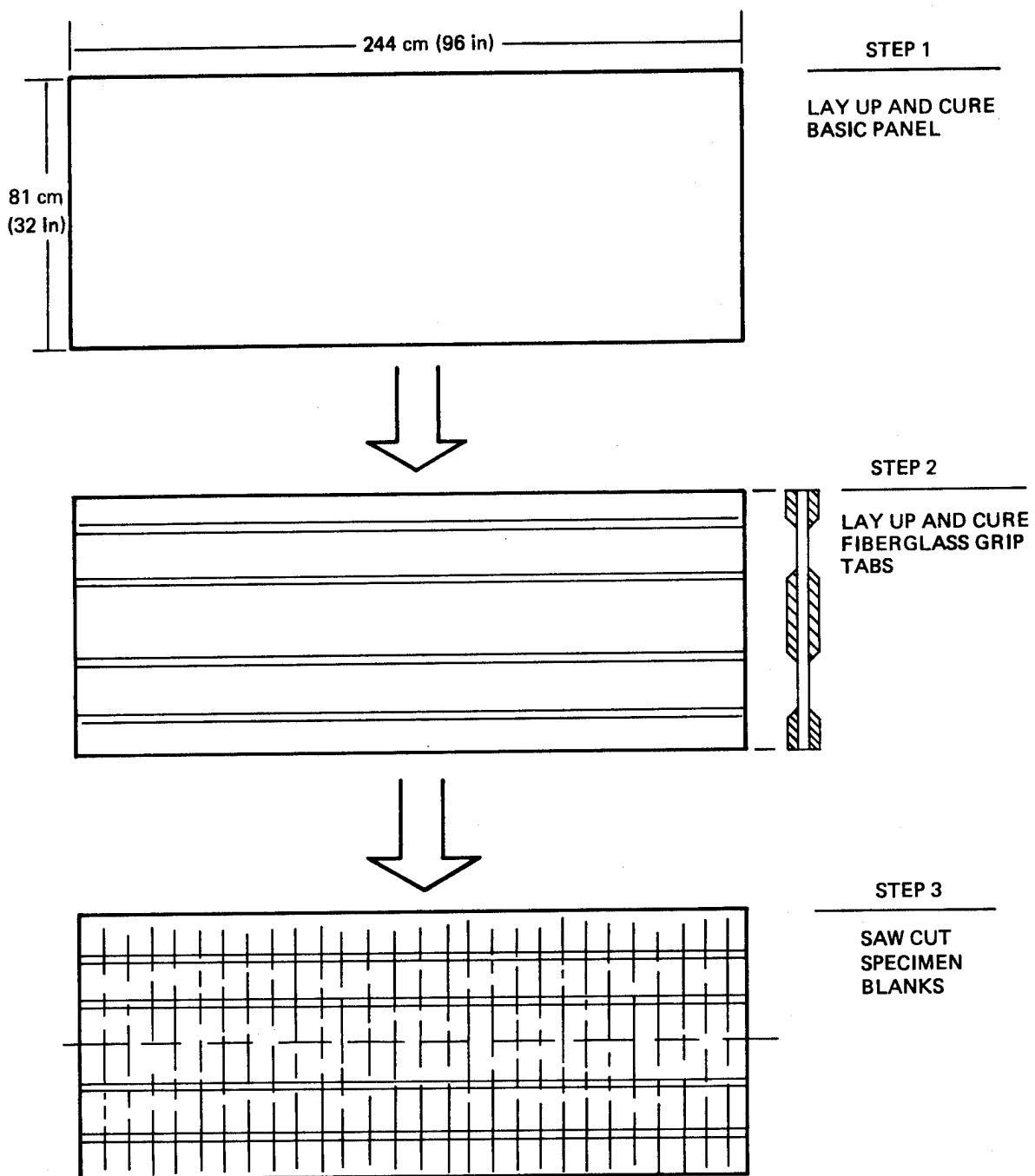


Figure 4. Test Specimen Fabrication Sequence

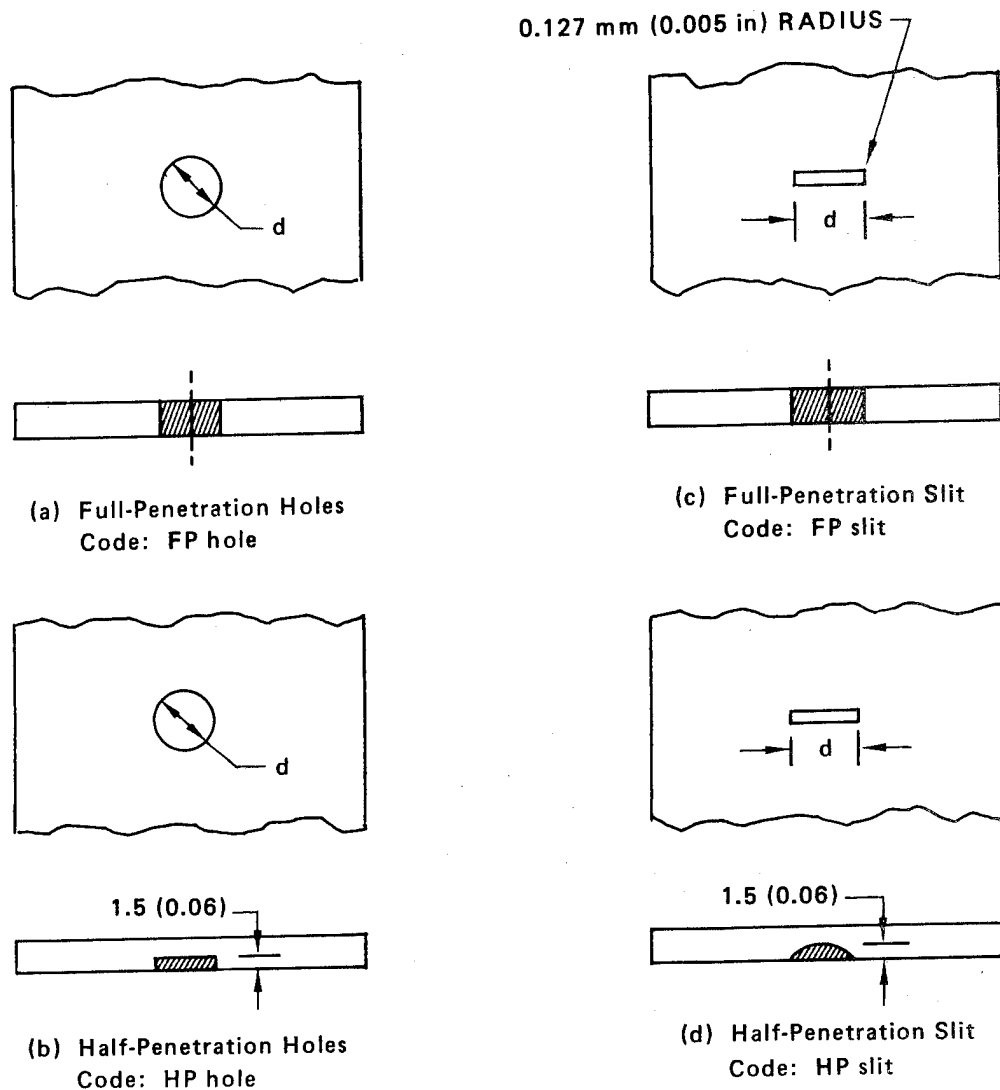


Figure 5. Stress Concentration Configurations Tested

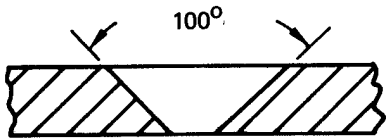


| LAMINATE | DEFECT |
|----------|--|
| L1 |  <p>DEEP COUNTERSINK</p> |
| L2 |  <p>VOIDS</p> |
| L3 |  <p>NO HYBRID FIBERS</p> |

Figure 6. Natural Defect Configurations Tested for Each Laminate Type

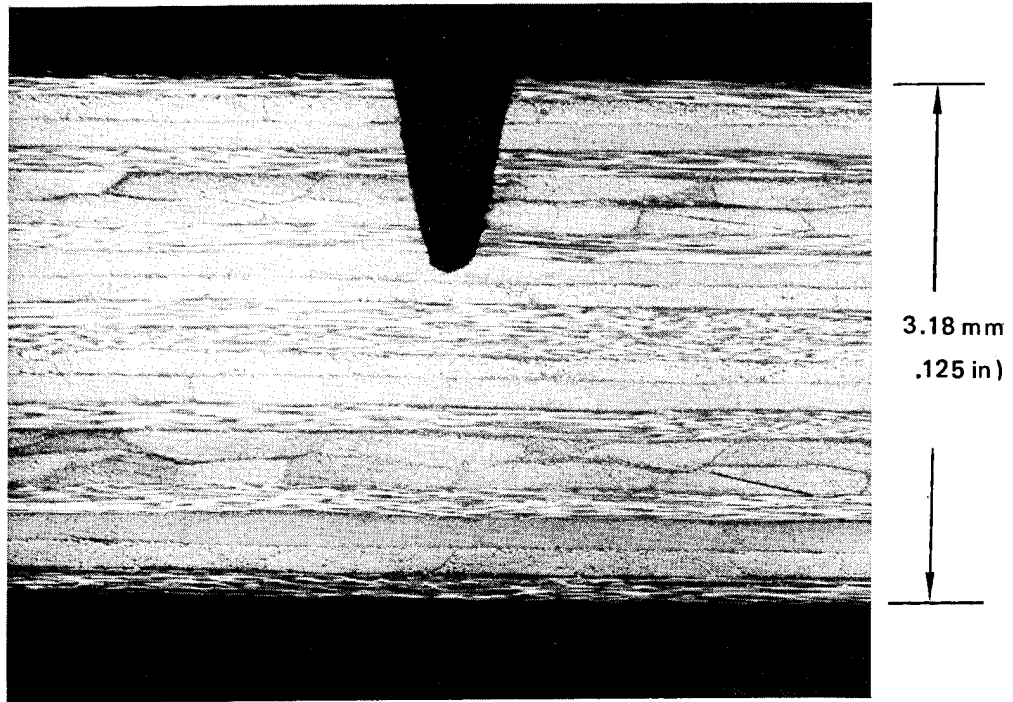
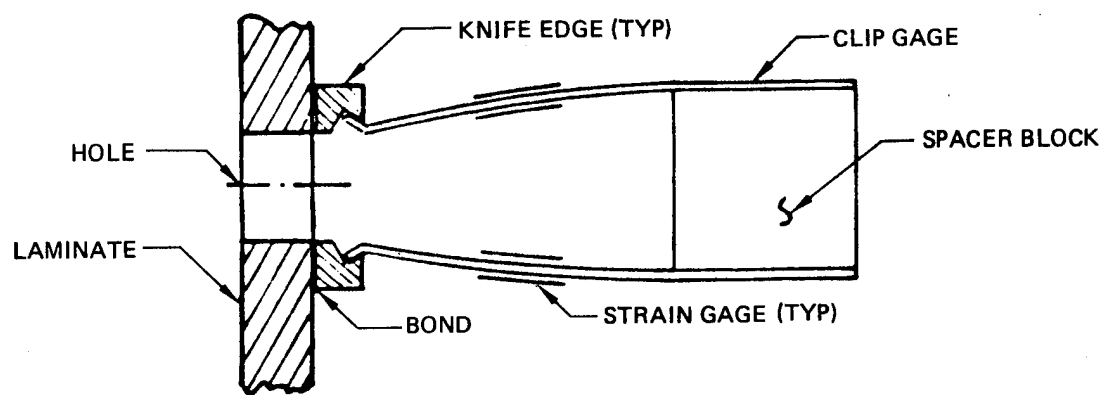
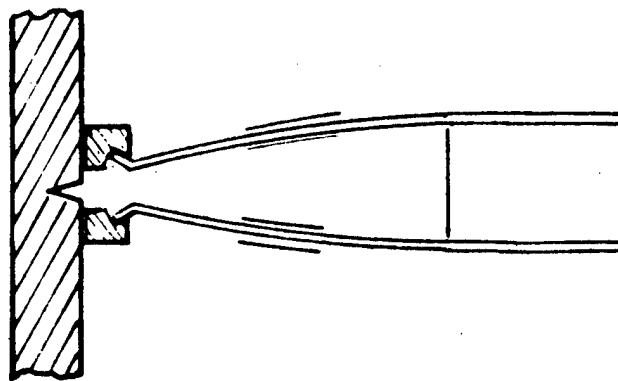


Figure 7. Photomicrograph Showing Root of Ultrasonic Flaw



SECTION A-A FOR CIRCULAR HOLES



SECTION A-A FOR SLITS

Figure 8. Clip Gage Installation on Test Specimens Containing Defects

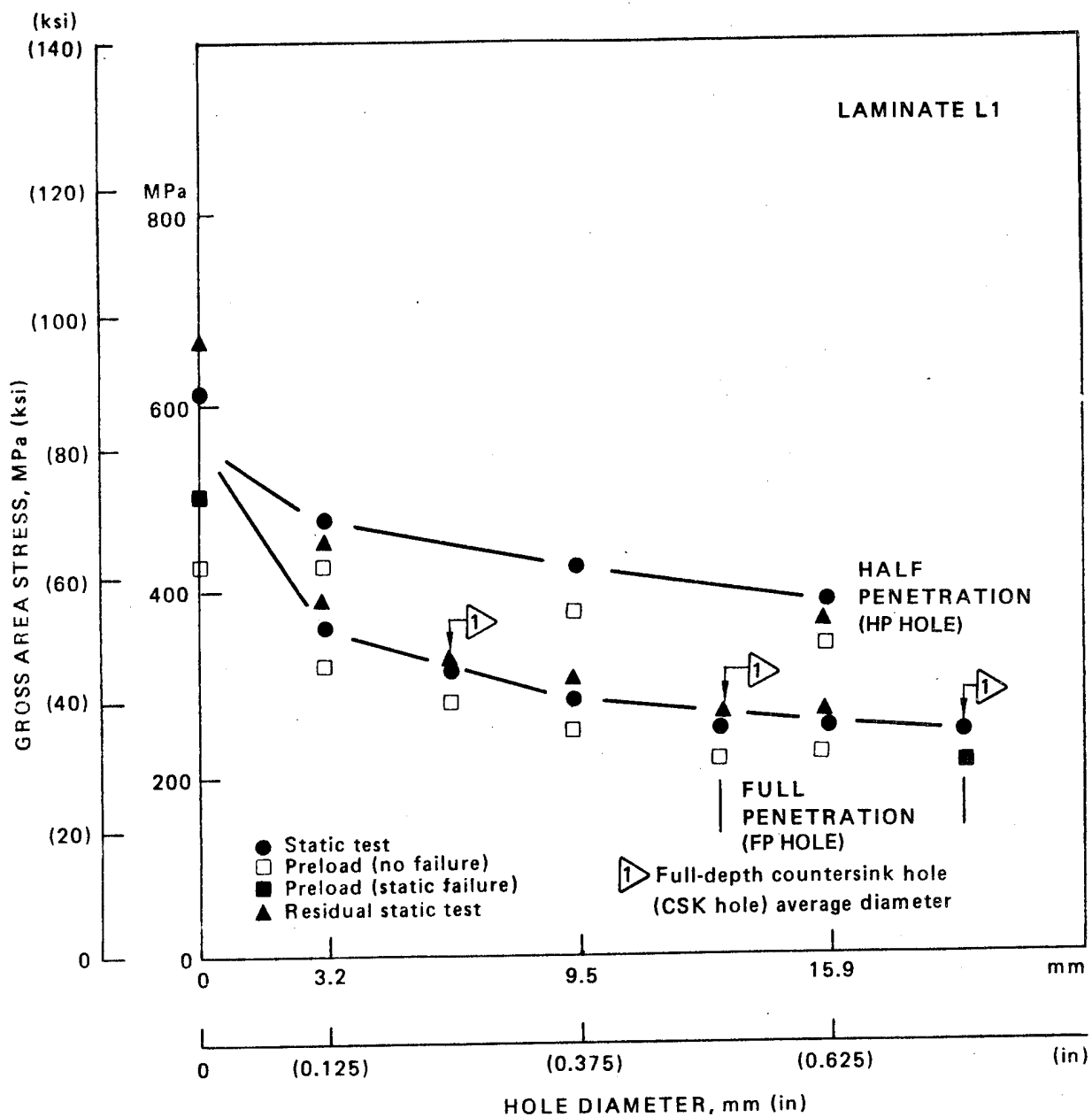


Figure 9. Static Test Results for Laminate L1 Specimens With Holes

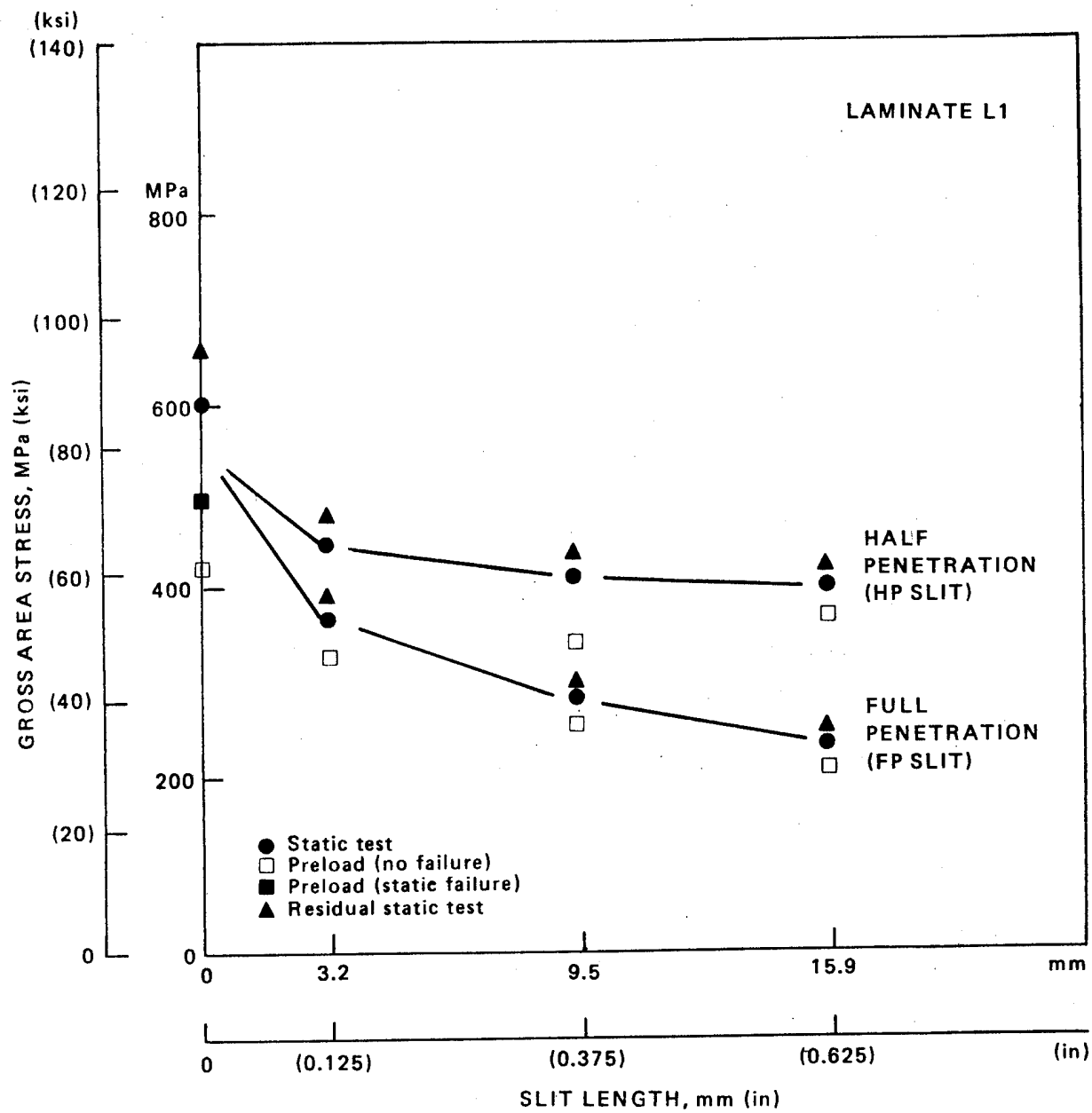


Figure 10. Static Test Results for Laminate L1 Specimens With Slits

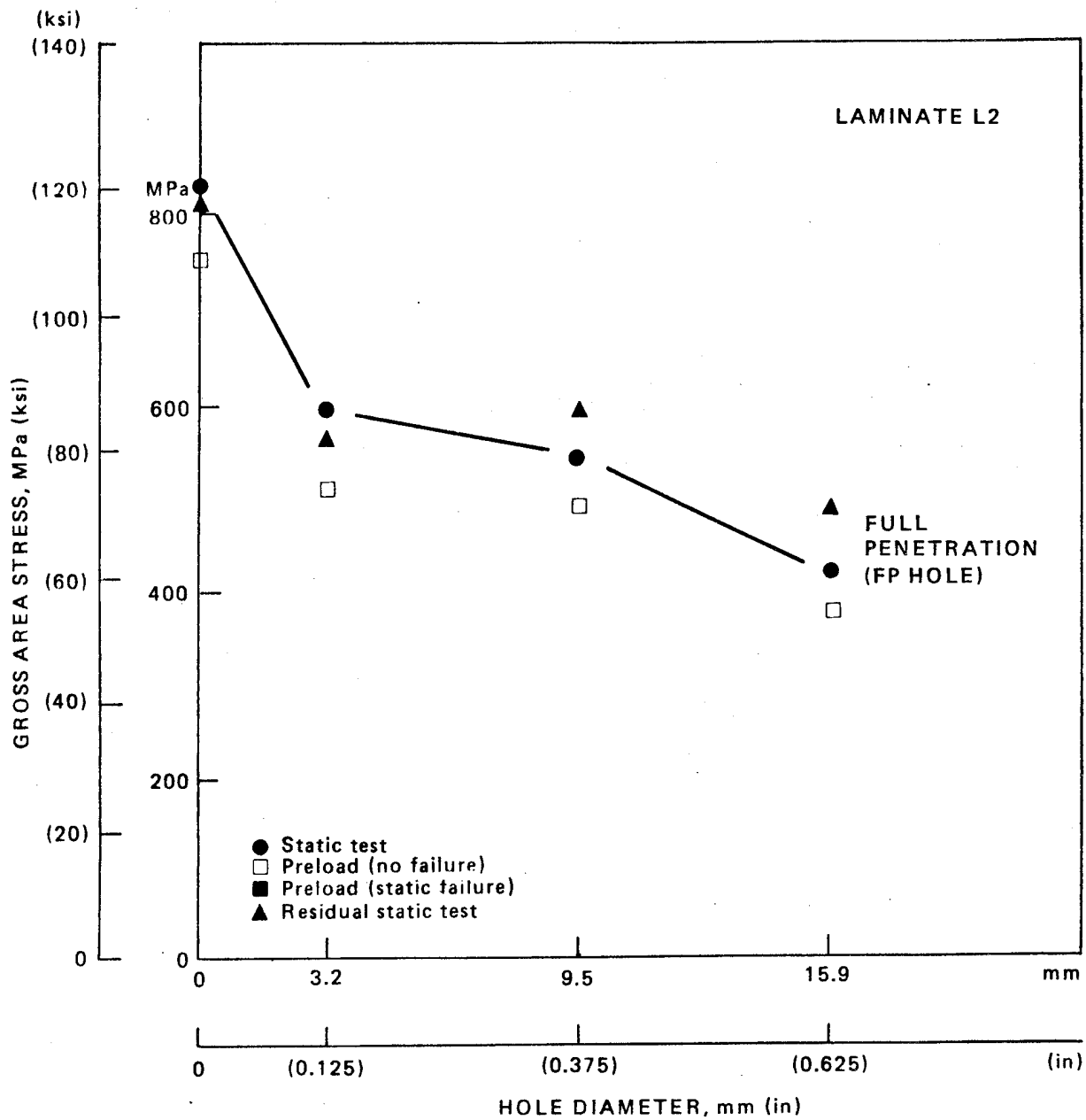


Figure 11. Static Test Results for Laminate L2 Specimens With Holes

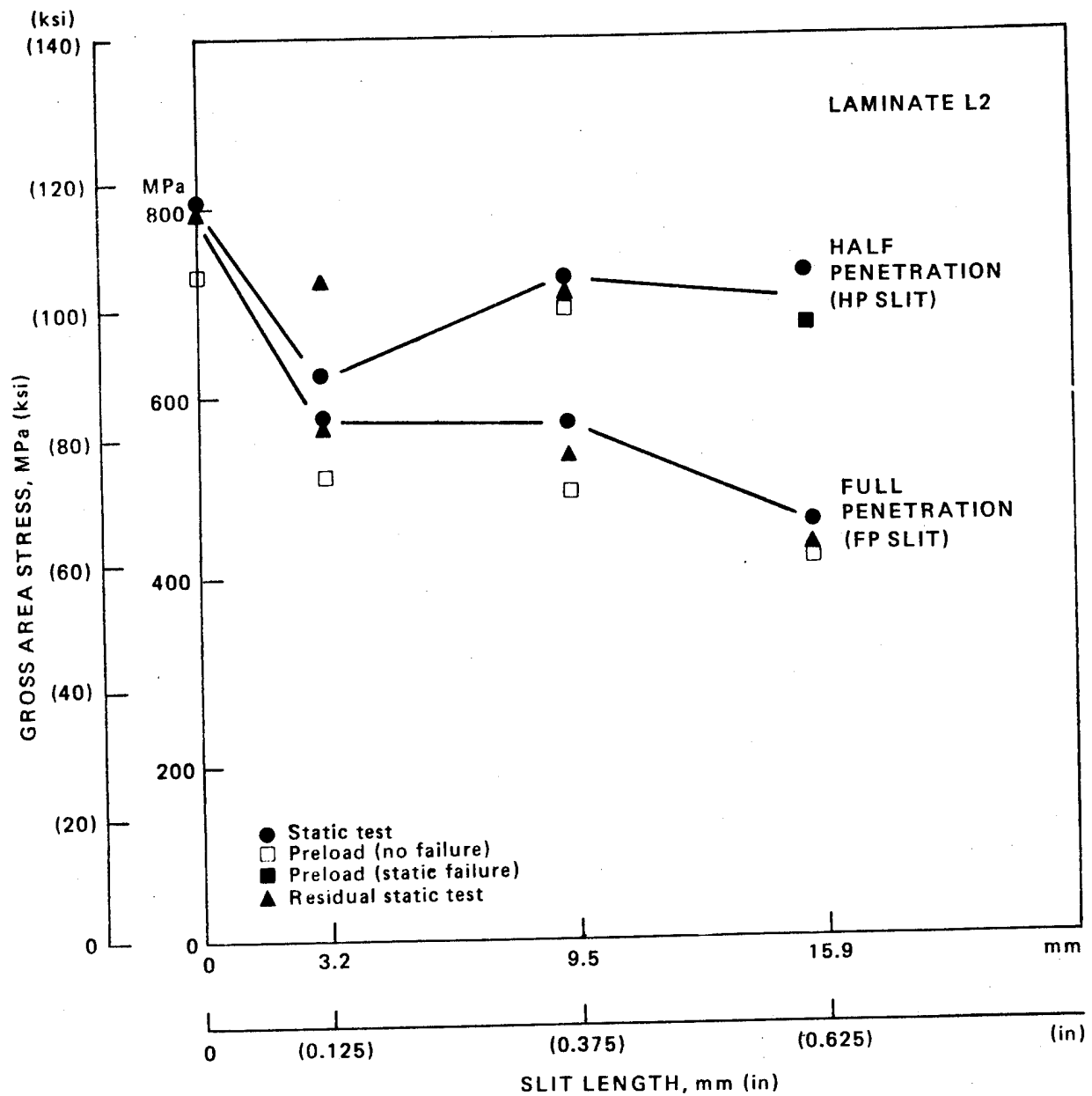


Figure 12. Static Test Data for Laminate L2 Specimens With Slits

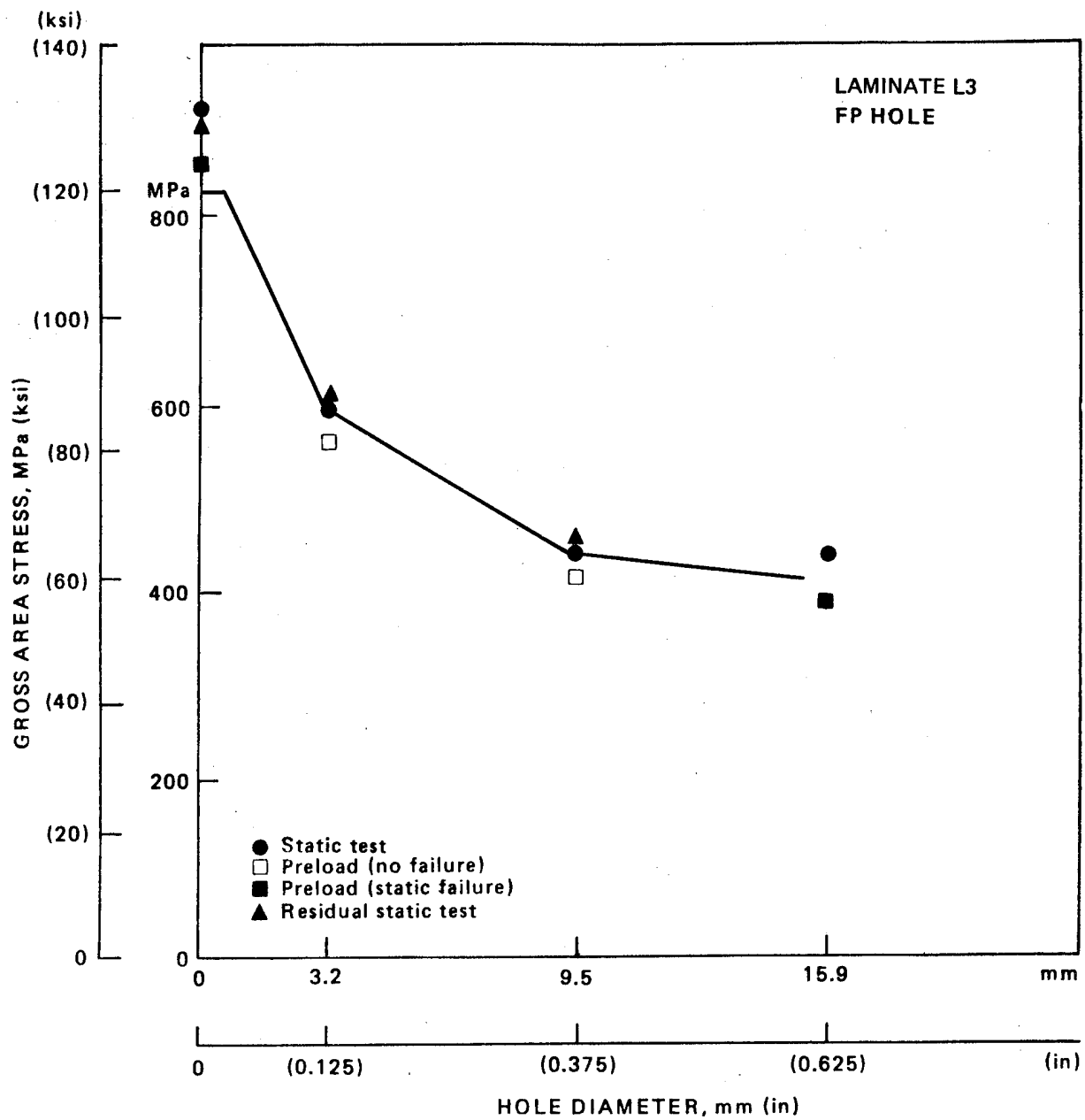


Figure 13. Static Test Results for Laminate L3 Specimens With Holes

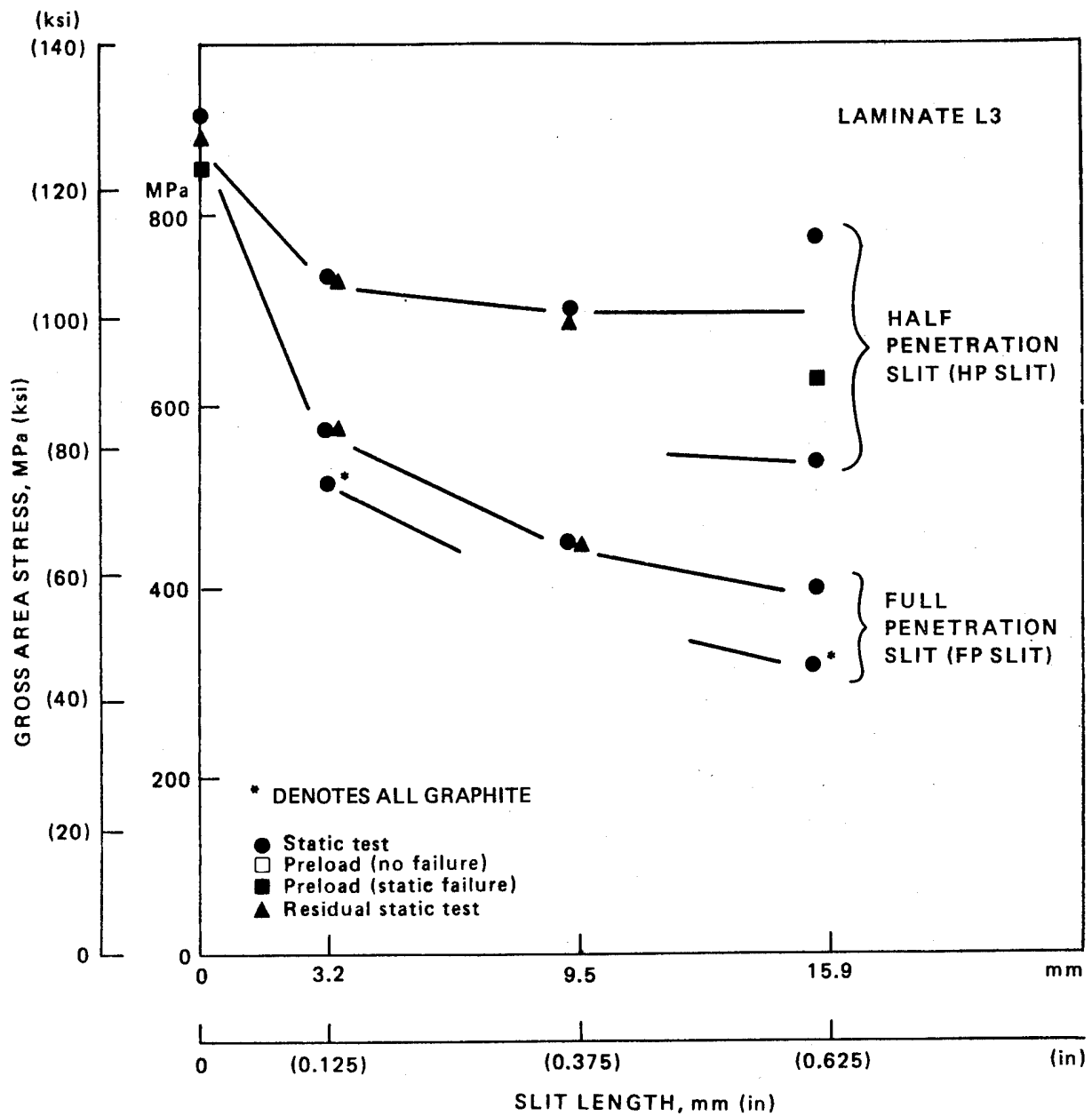


Figure 14. Static Test Results for Laminate L3 Specimens With Slits

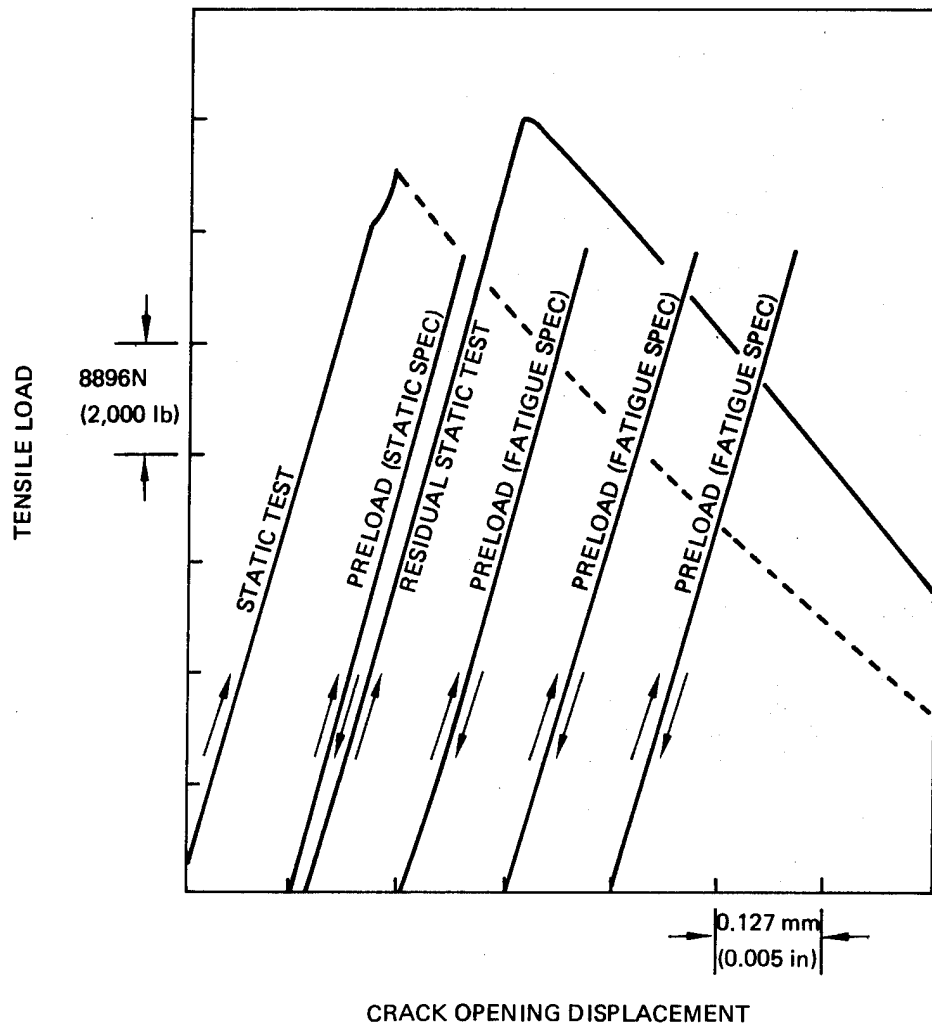


Figure 15. Crack Opening Displacement Records for Laminate L1
Specimens With Full-Penetration Hole

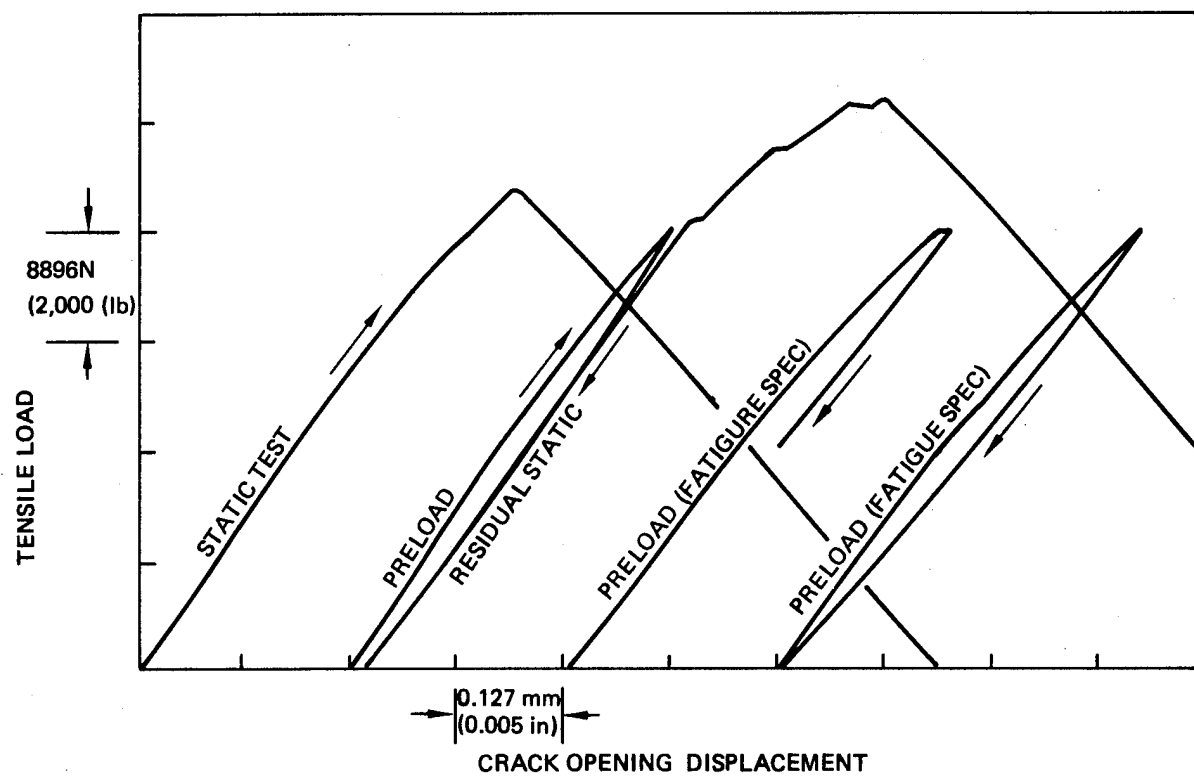


Figure 16. Crack Opening Displacement Records for Laminate L2
Specimens With Full-Penetration Hole

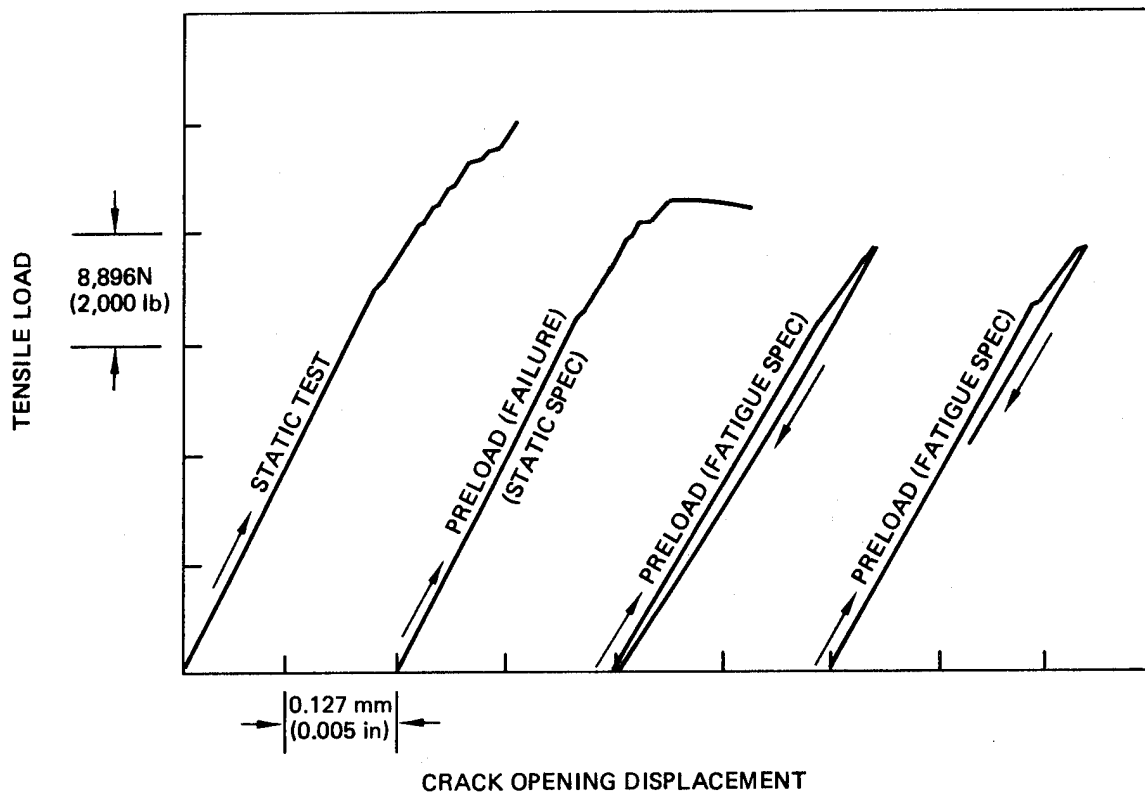


Figure 17. Crack Opening Displacement Records for Laminate L3
Specimens With Full-Penetration Hole

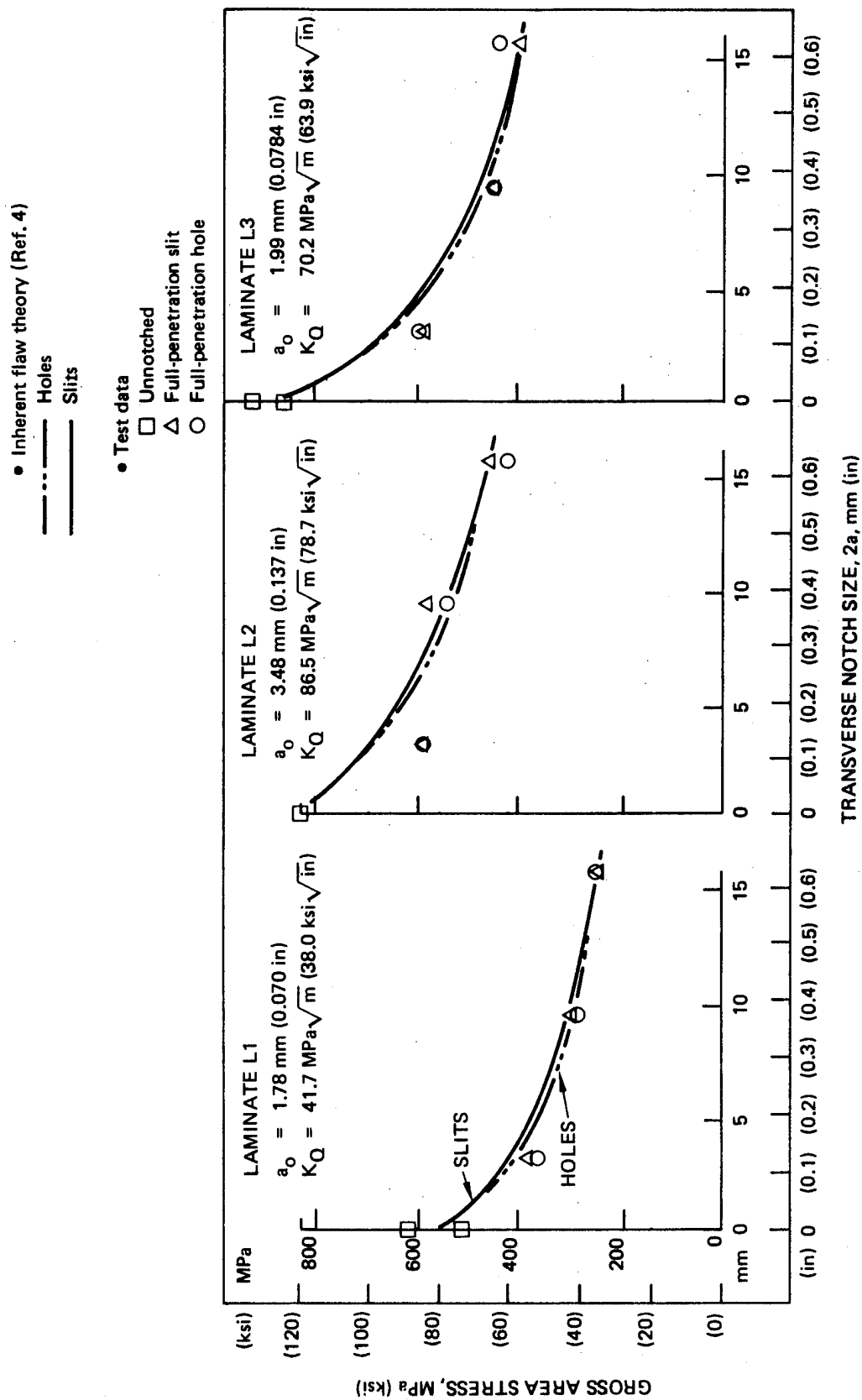


Figure 18. Comparison of Inherent Flaw Analysis and Static Test Data

● Average stress theory (Ref. 5)

--- Holes

— Slits

● Test data

□ Unnotched

△ Full-penetration slit

○ Full-penetration hole

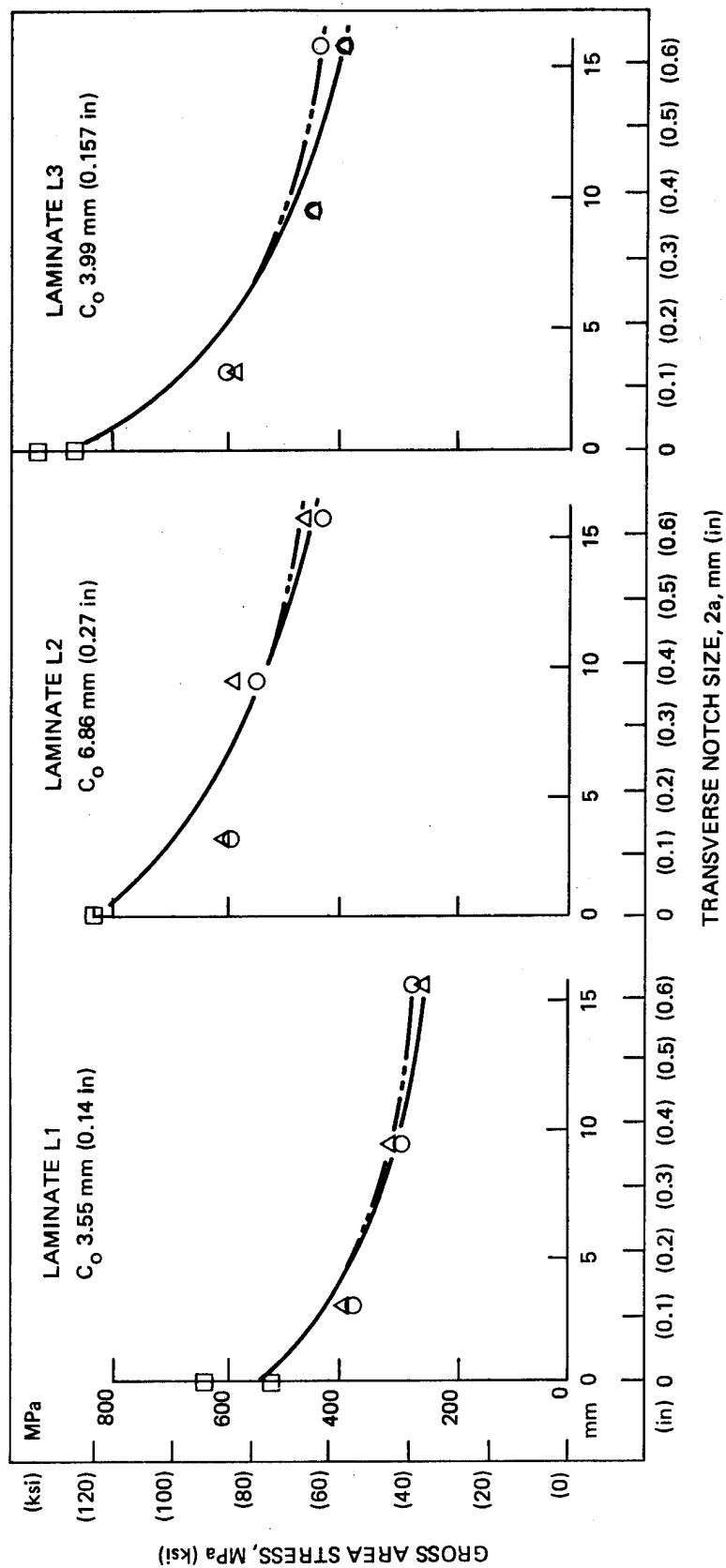
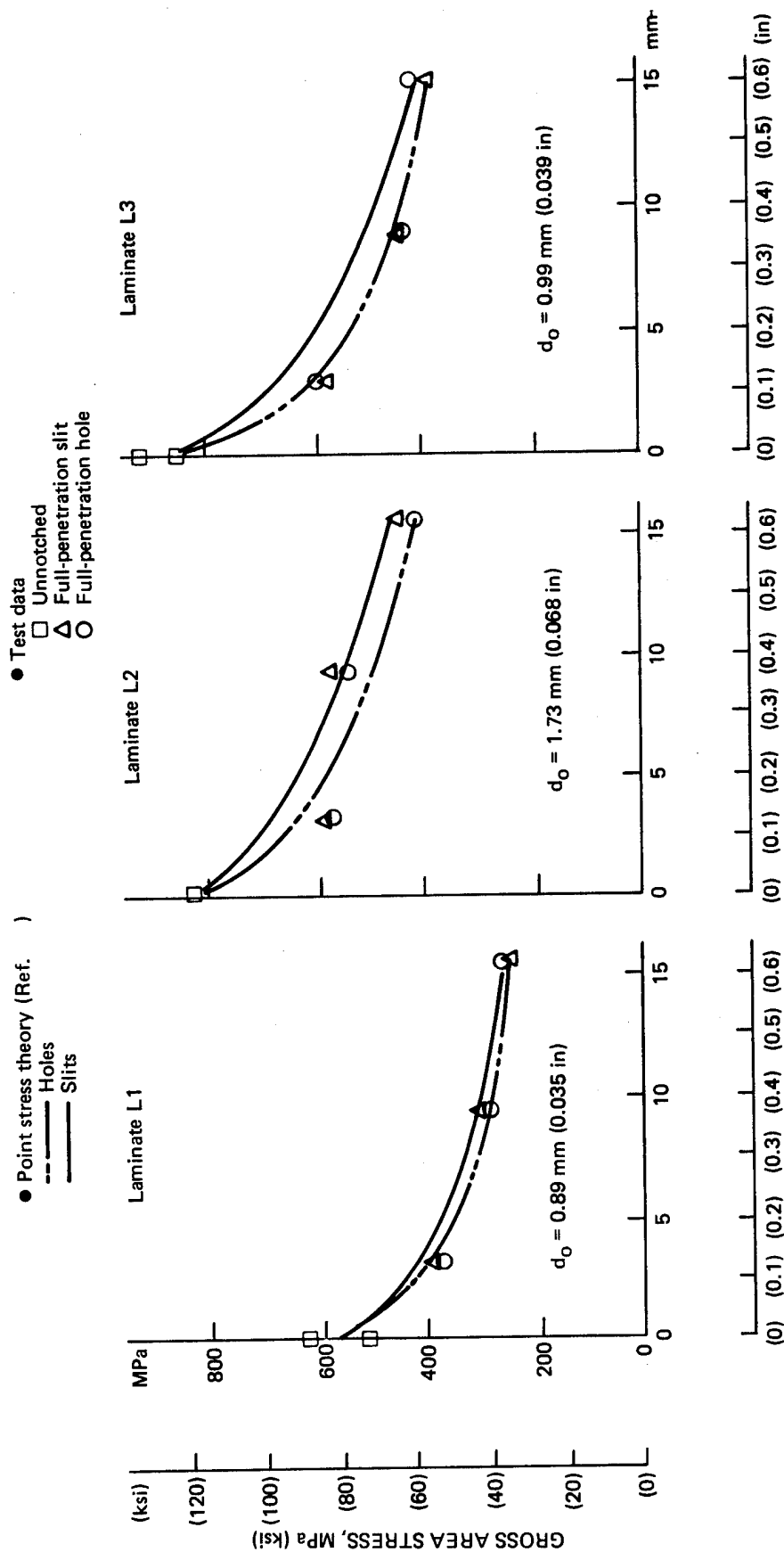


Figure 19. Comparison of Average Stress Analysis and Static Test Data



TRANSVERSE NOTCH SIZE, 2a, mm (in)

Figure 20. Comparison of Point Stress Analysis and Static Test Data

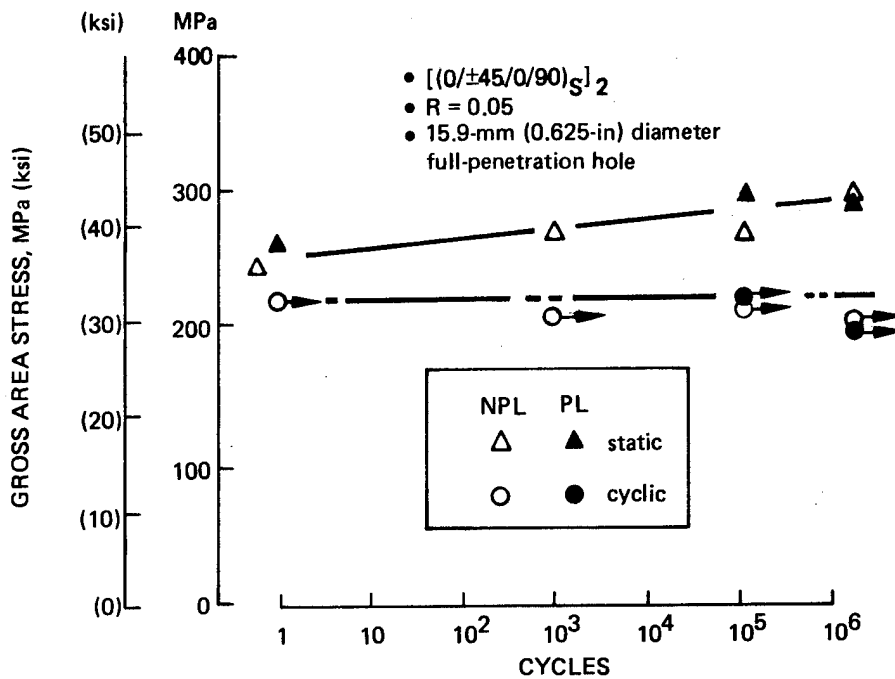


Figure 21. Fatigue Data for Laminate L1 5/8 FP Hole

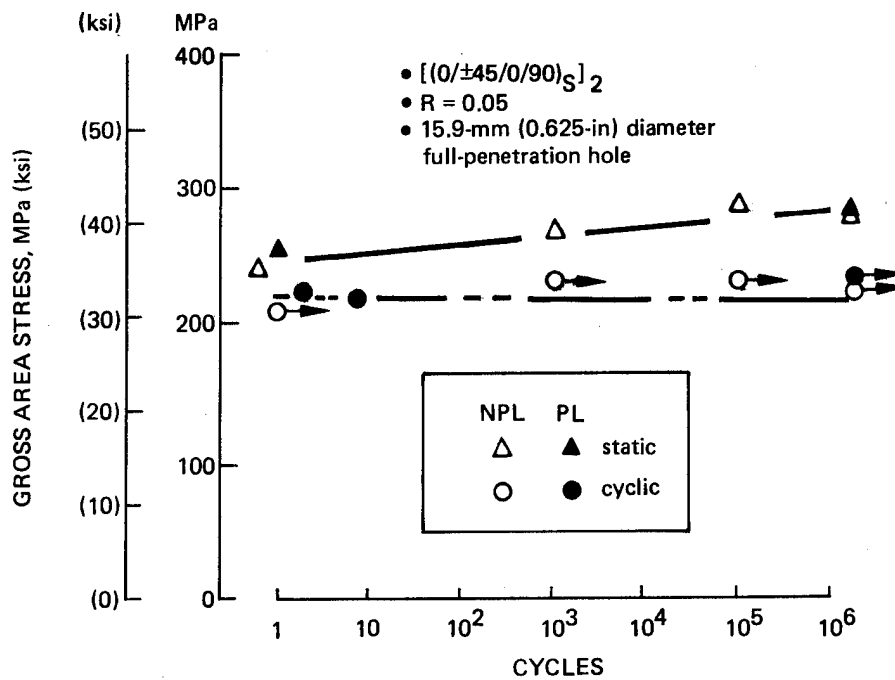


Figure 22. Fatigue Data for Laminate L1 5/8 FP Slit

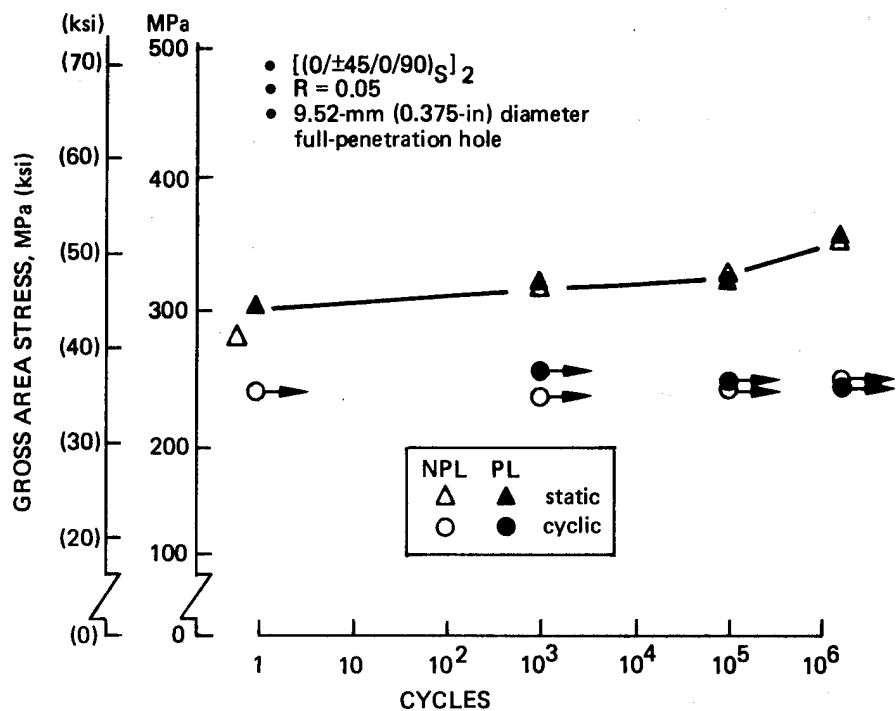


Figure 23. Fatigue Data for Laminate L1 3/8 FP Hole

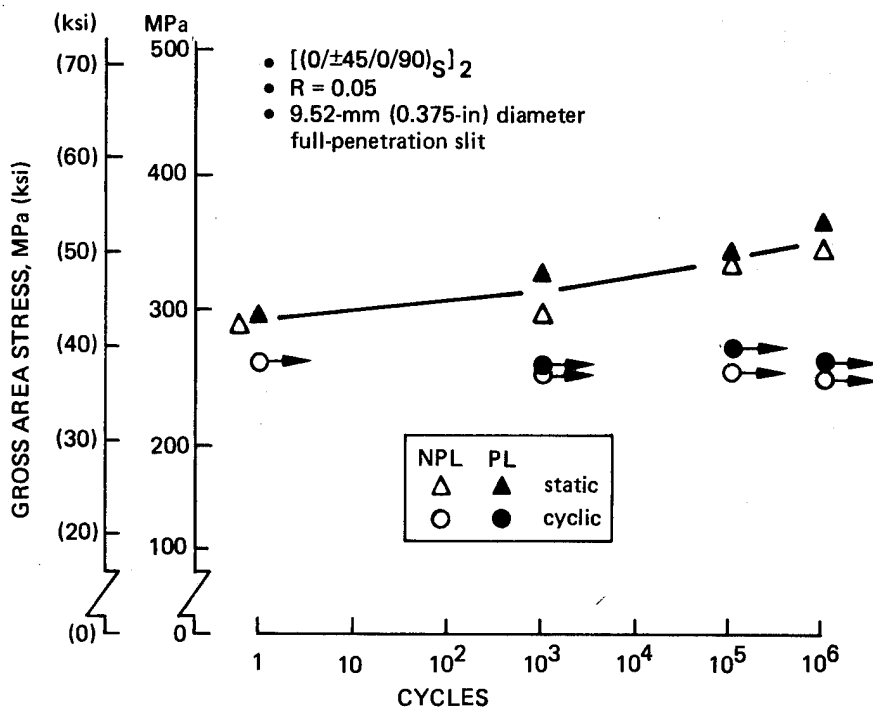


Figure 24. Fatigue Data for Laminate L1 3/8 FP Slit

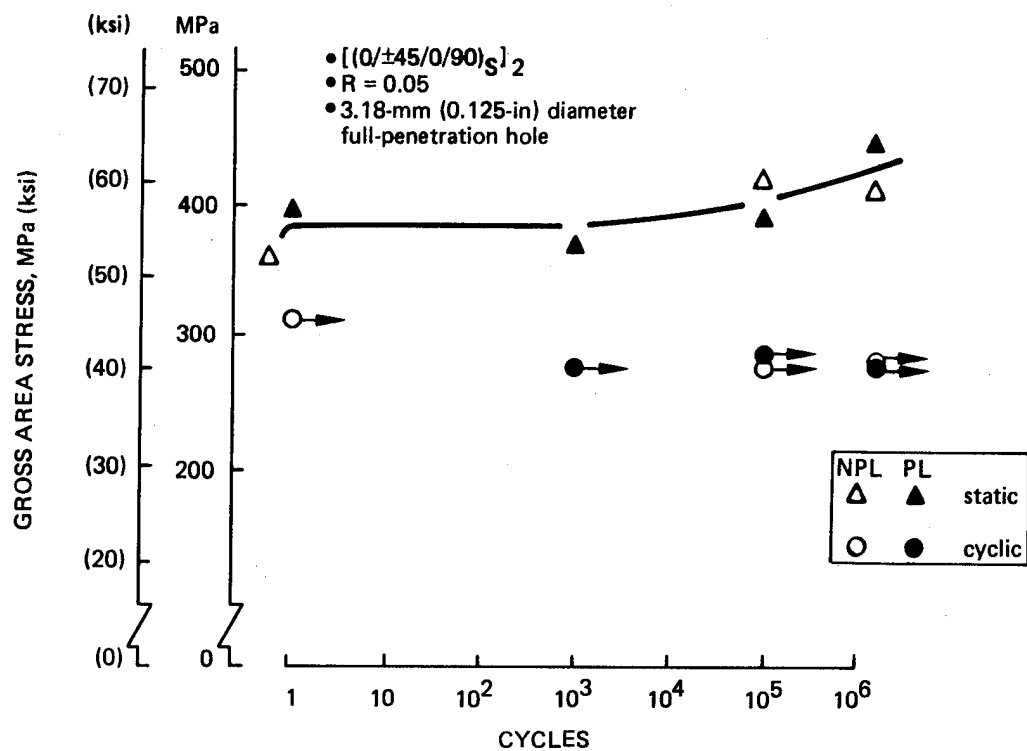


Figure 25. Fatigue Data for Laminate L1 1/8 FP Hole

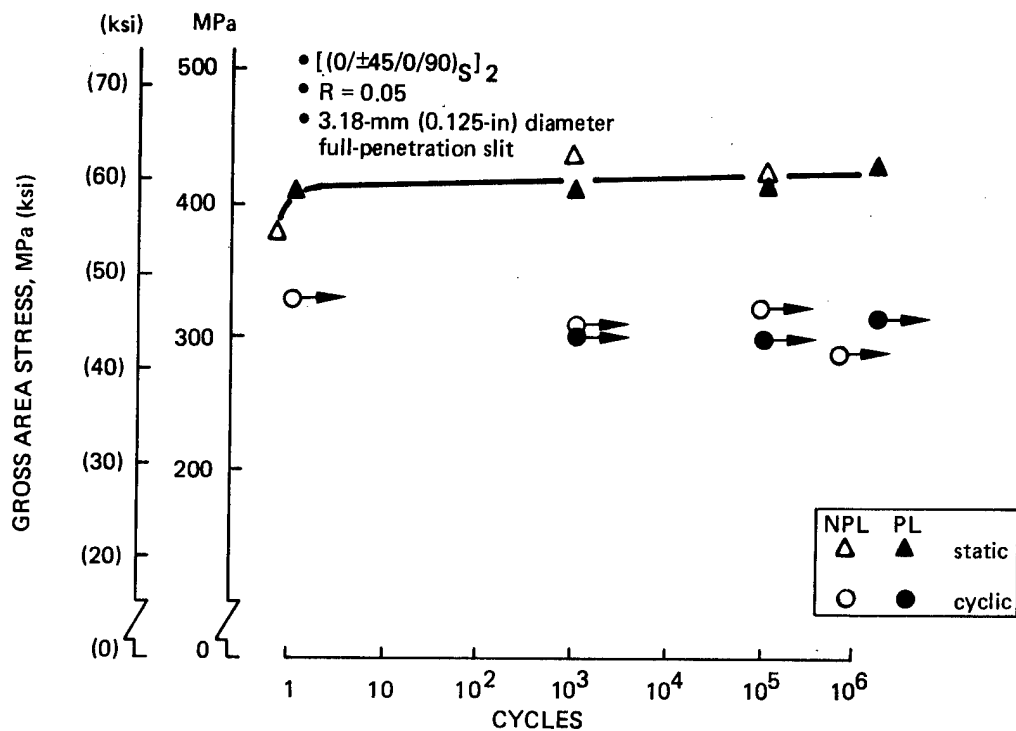


Figure 26. Fatigue Data for Laminate L1 1/8 FP Slit

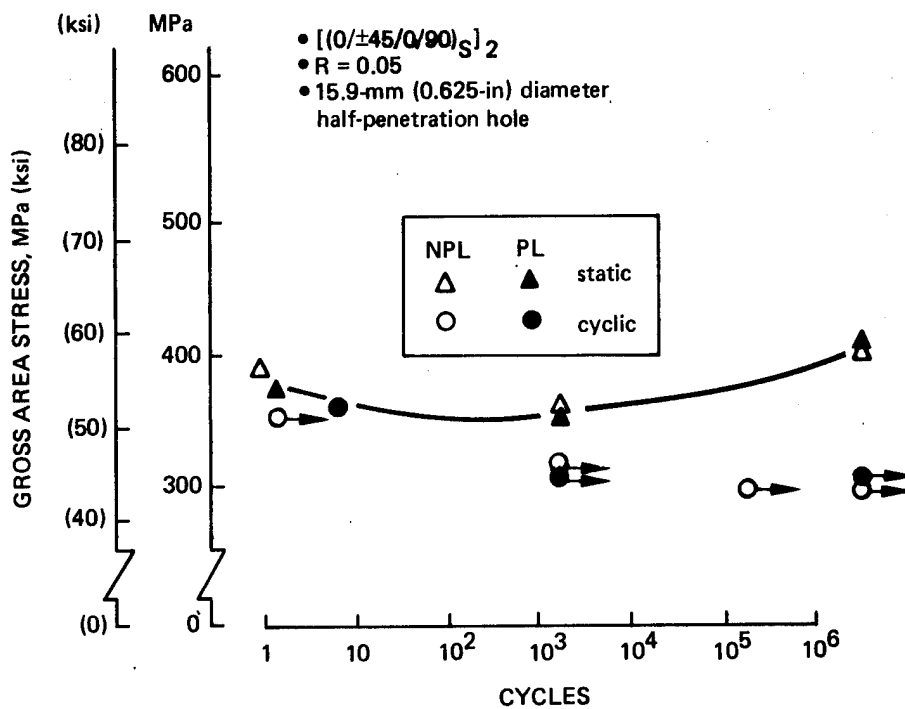


Figure 27. Fatigue Data for Laminate L1 5/8 HP Hole

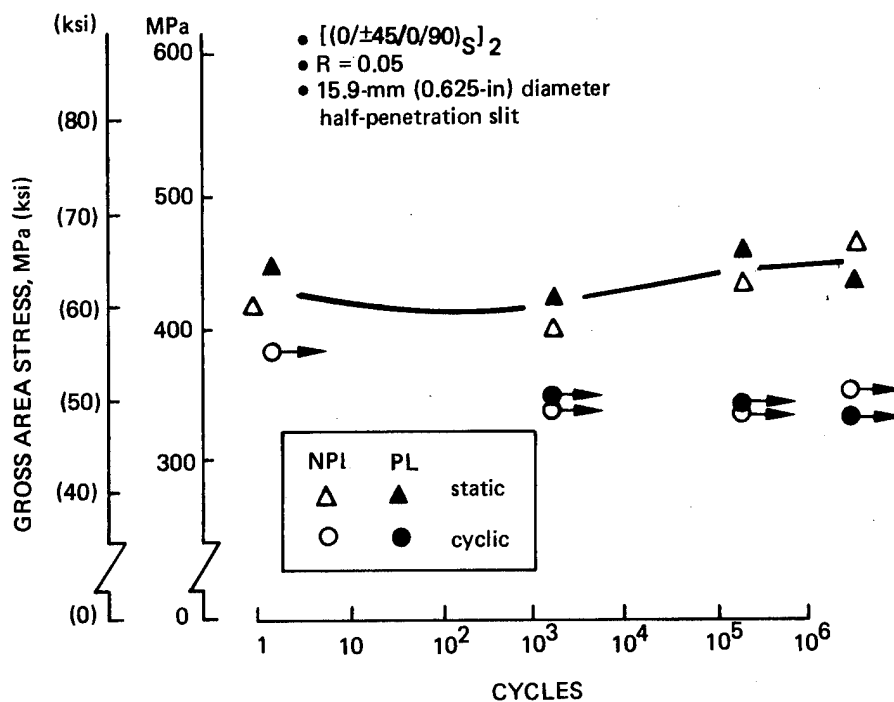


Figure 28. Fatigue Data for Laminate L1 5/8 HP Slit

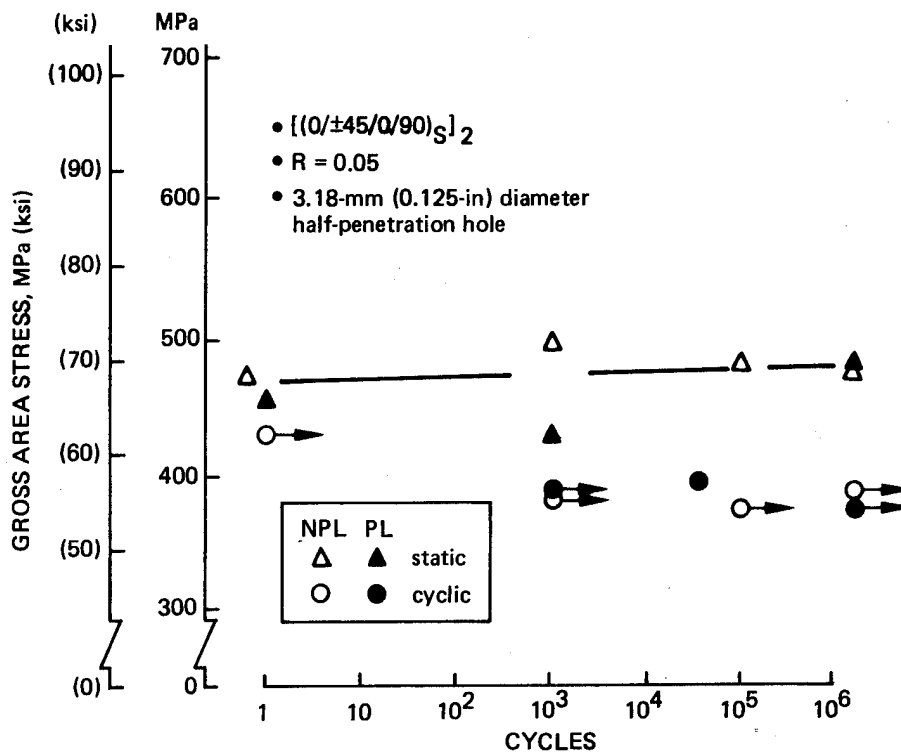


Figure 29. Fatigue Data for Laminate L1 1/8 HP Hole

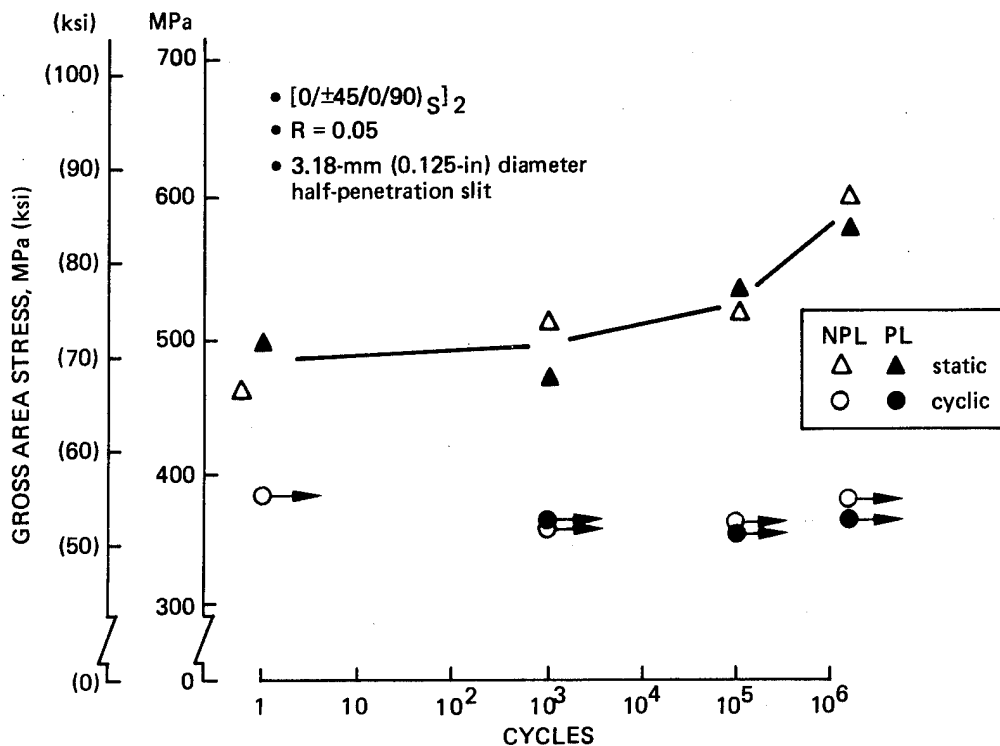


Figure 30. Fatigue Data for Laminate L1 1/8 HP Slit

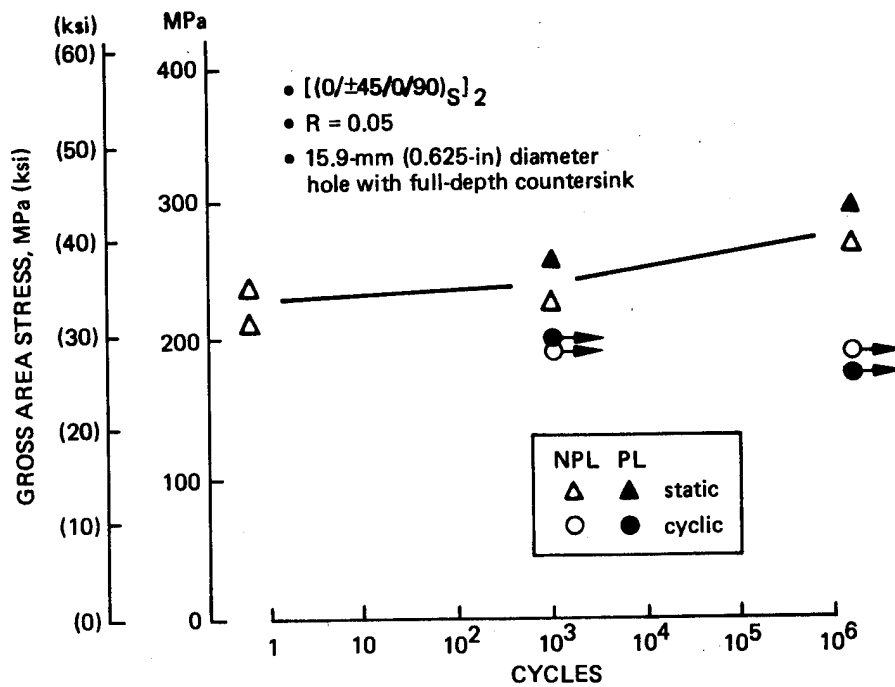


Figure 31. Fatigue Data for Laminate L1 5/8 CSK Hole

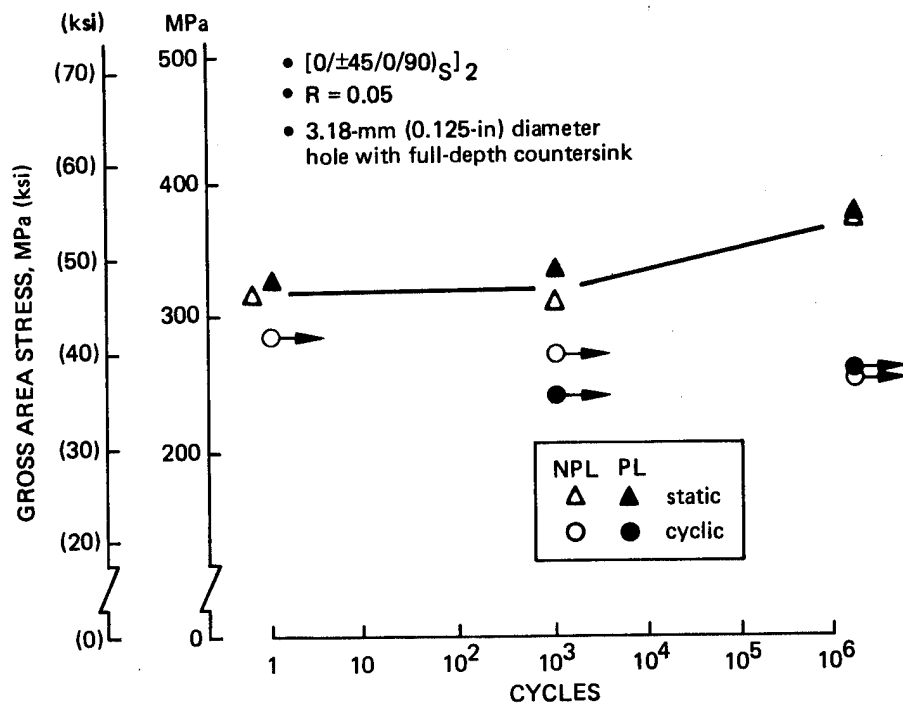


Figure 32. Fatigue Data for Laminate L1 1/8 CSK Hole

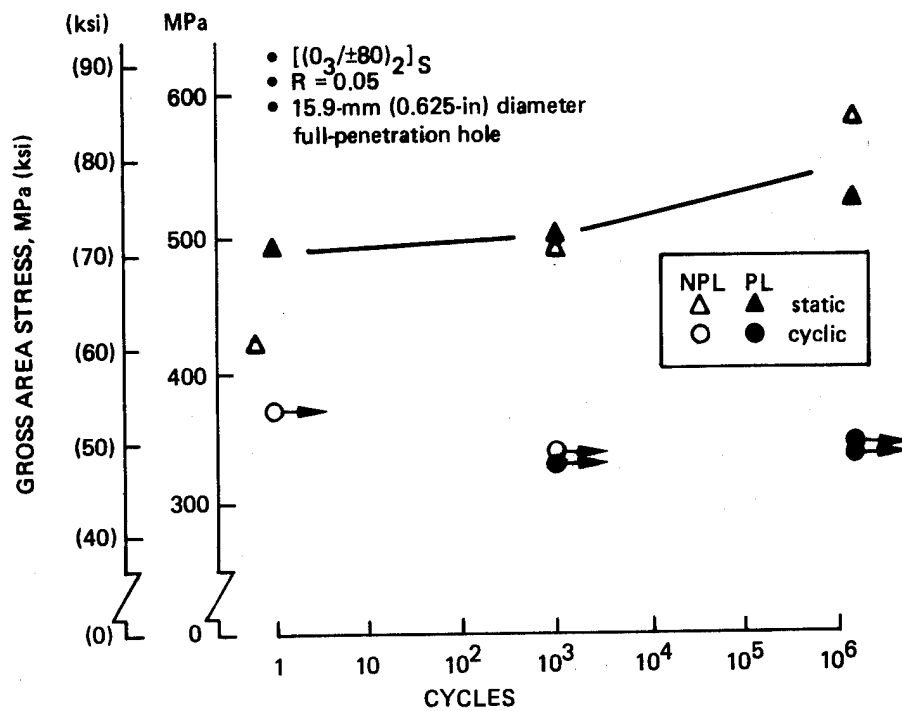


Figure 34. Fatigue Data for Laminate L2 5/8 FP Hole

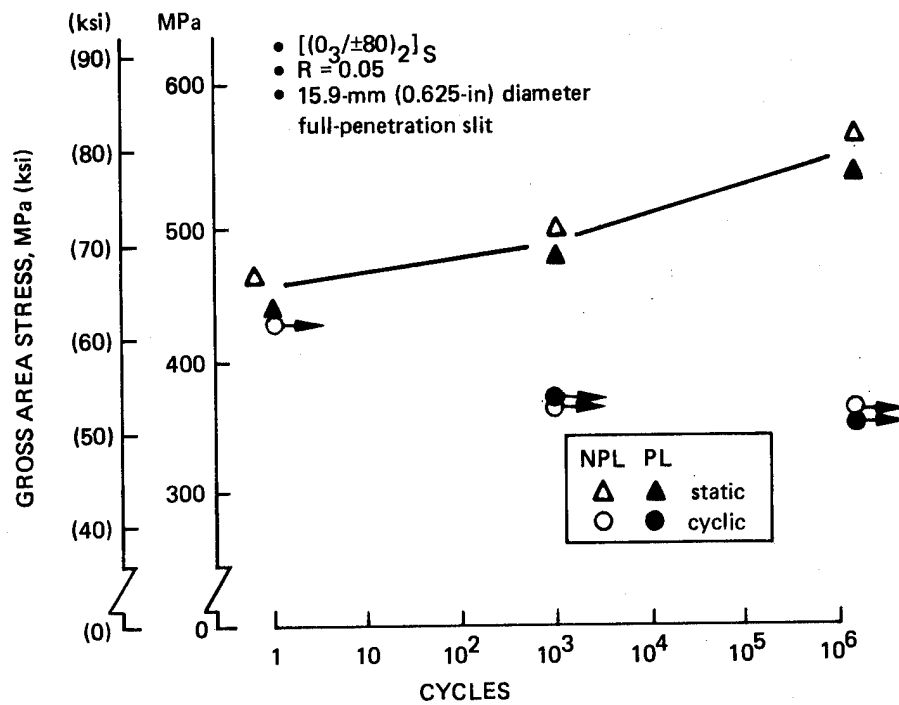


Figure 35. Fatigue Data for Laminate L2 5/8 FP Slit

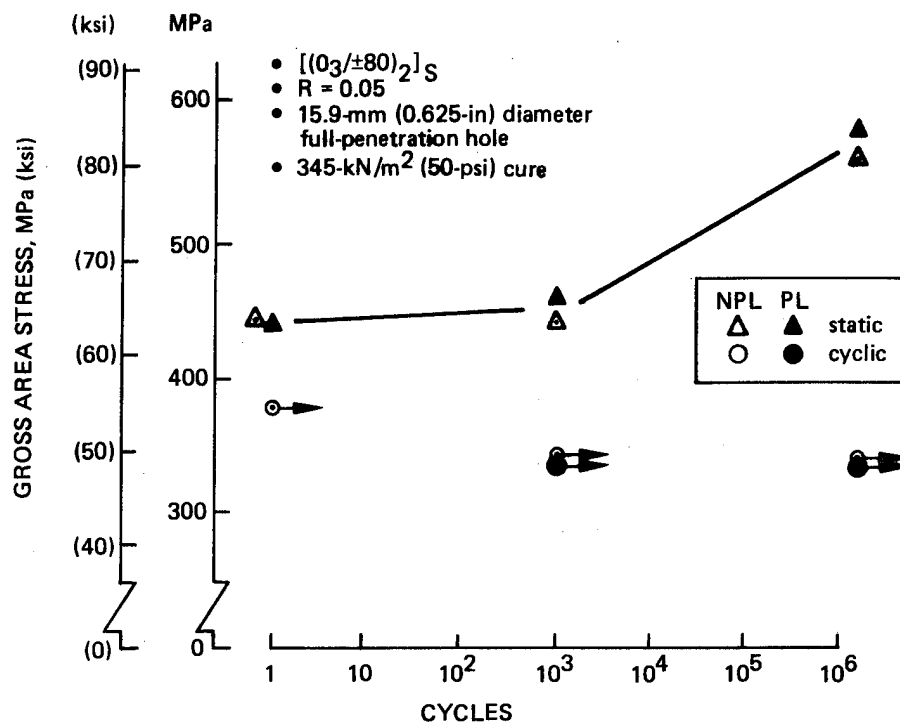


Figure 36. Fatigue Data for Laminate L2 With Low Cure Pressure and 5/8 FP Hole

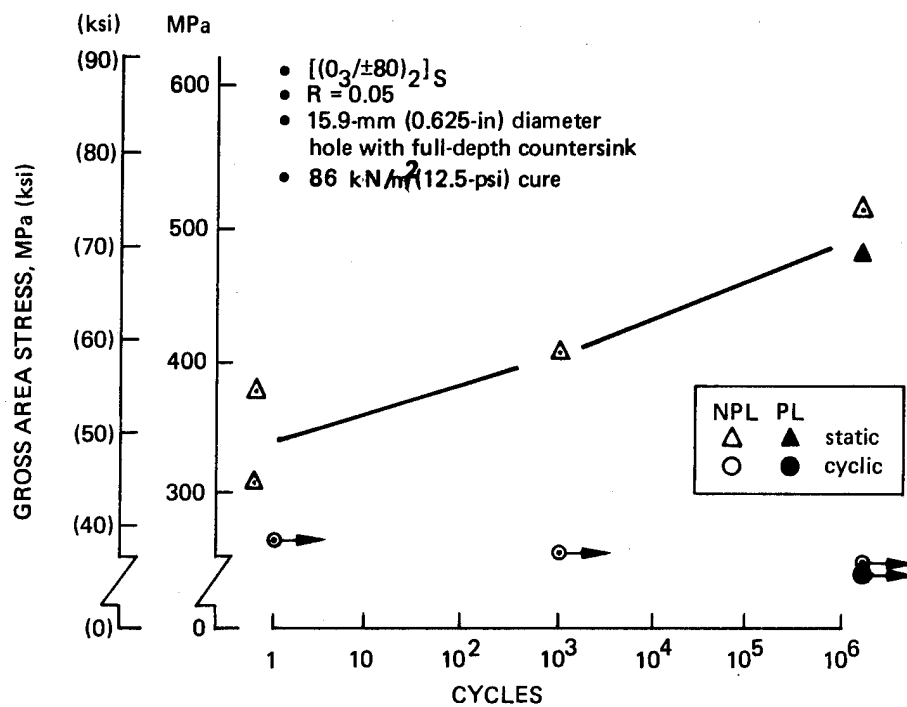


Figure 37. Fatigue Data for Laminate L2 With Low Cure Pressure and 5/8 CSK Hole

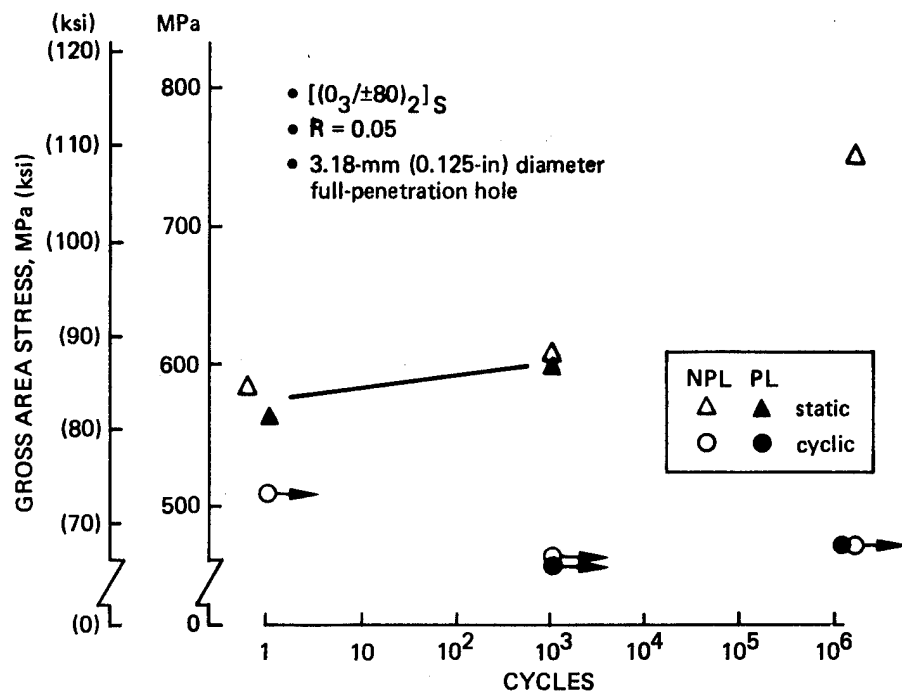


Figure 38. Fatigue Data for Laminate L2 1/8 FP Hole

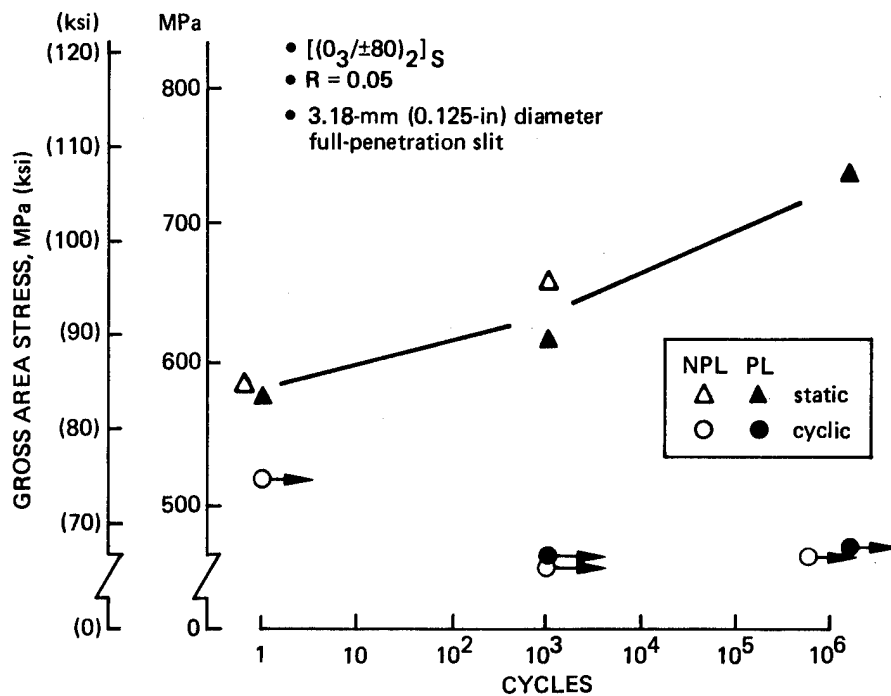


Figure 39. Fatigue Data for Laminate L2 1/8 FP Slit

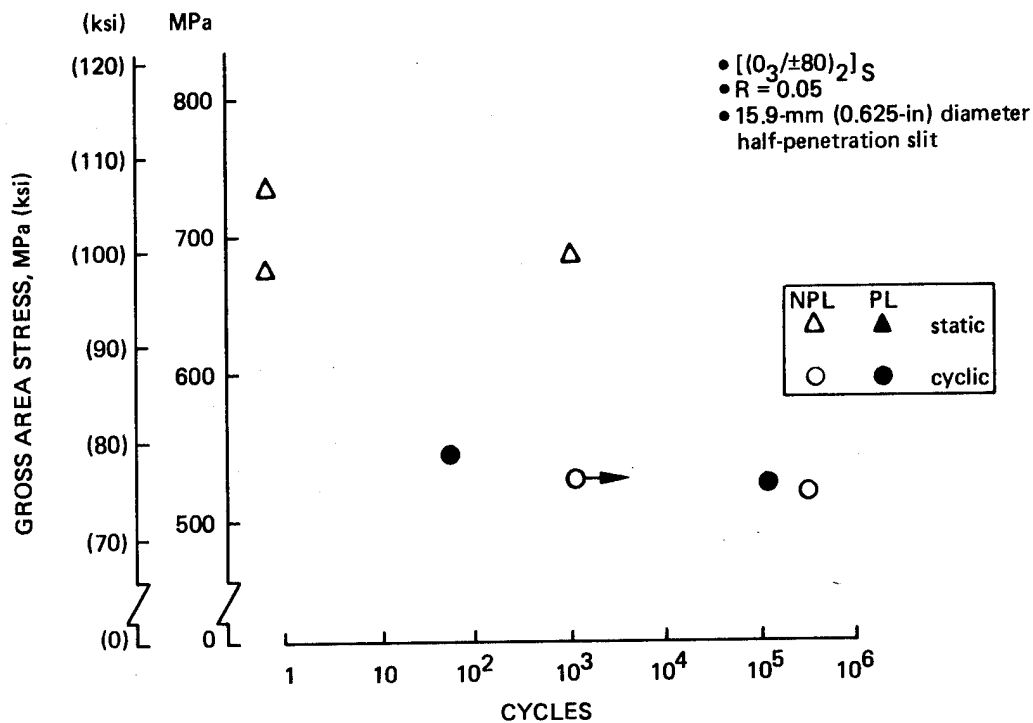


Figure 40. Fatigue Data for Laminate L2 5/8 HP Slit

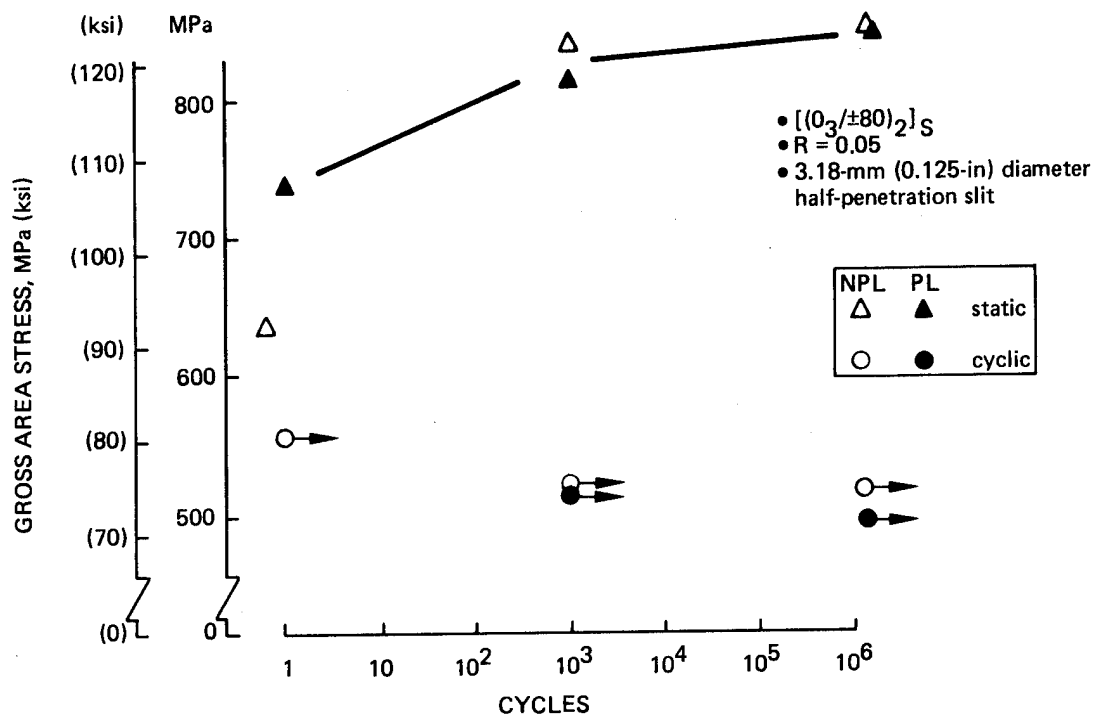


Figure 41. Fatigue Data for Laminate L2 1/8 HP Slit

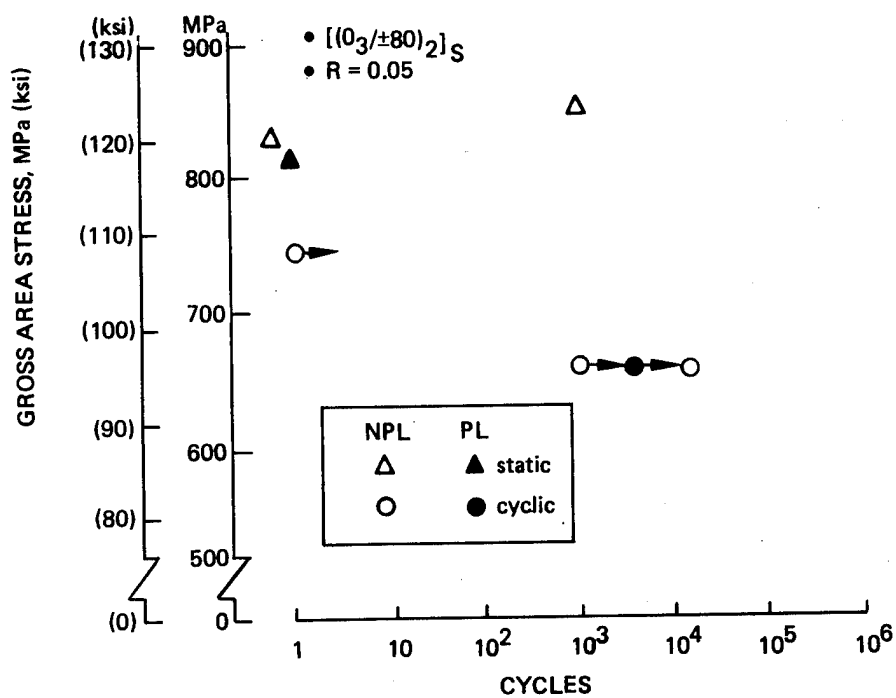


Figure 42. Fatigue Data for Laminate L2 Specimens With No Initial Defect

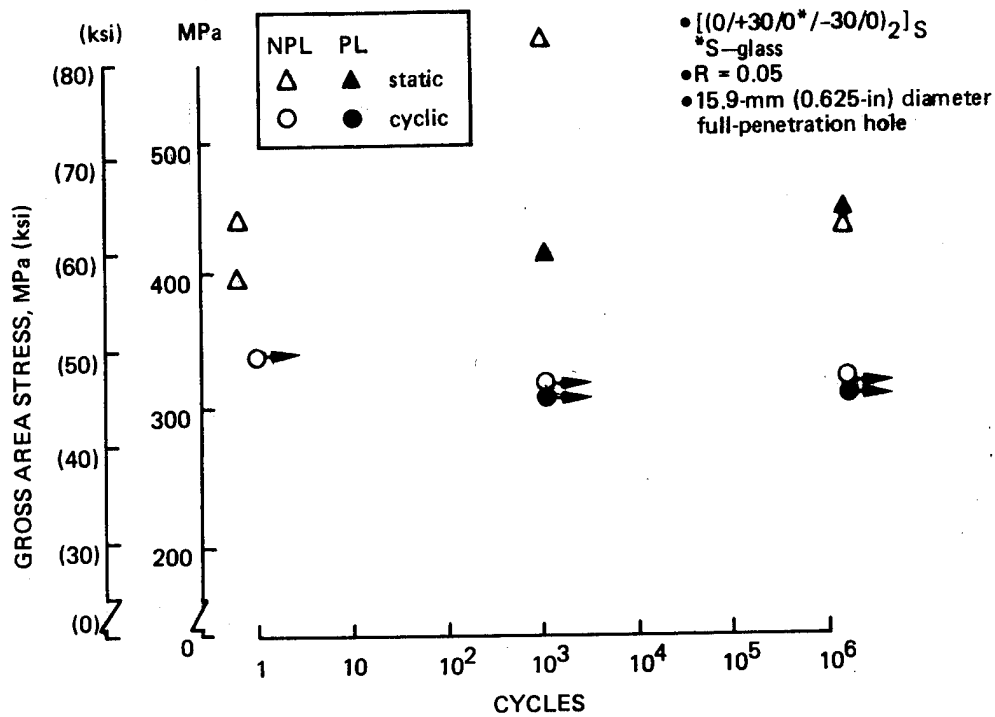


Figure 43. Fatigue Data for Laminate L3 5/8 FP Hole

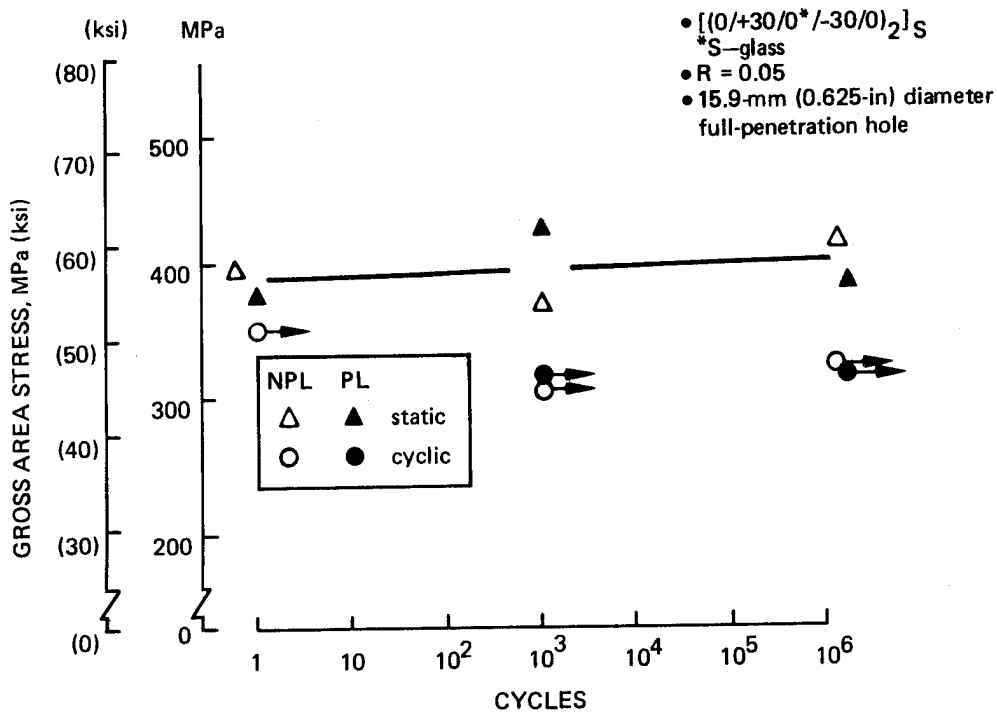


Figure 44. Fatigue Data for Laminate L3 5/8 FP Slit

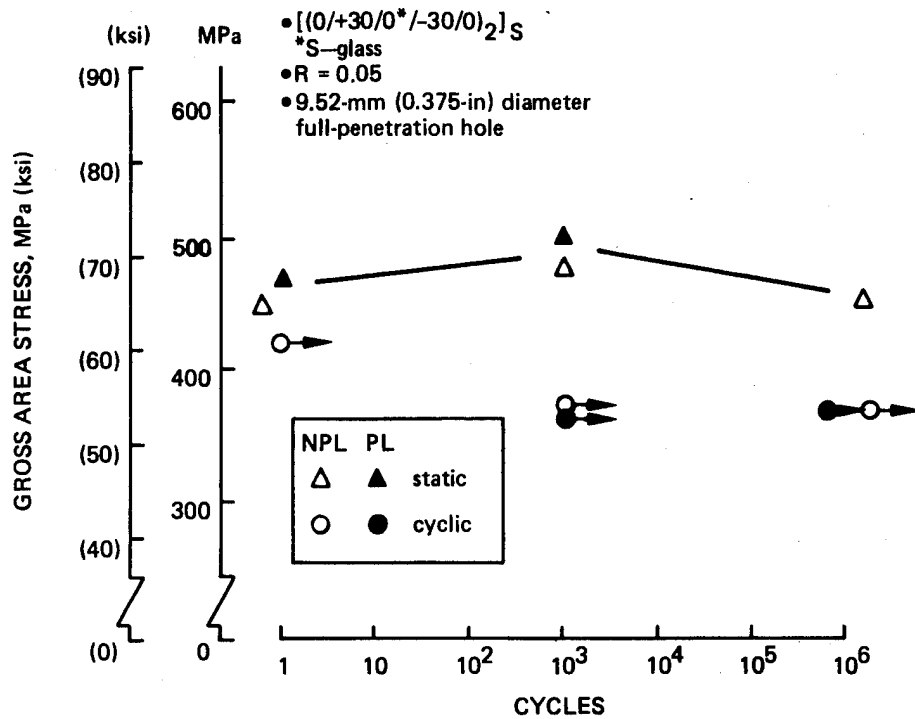


Figure 45. Fatigue Data for Laminate L3 3/8 FP Hole

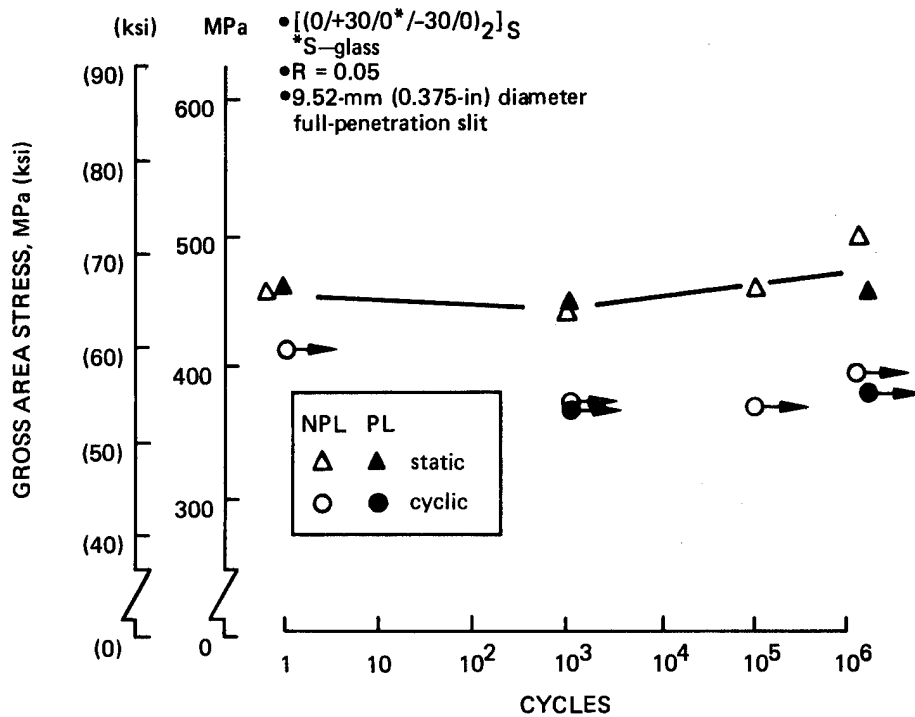


Figure 46. Fatigue Data for Laminate L3 3/8 FP Slit

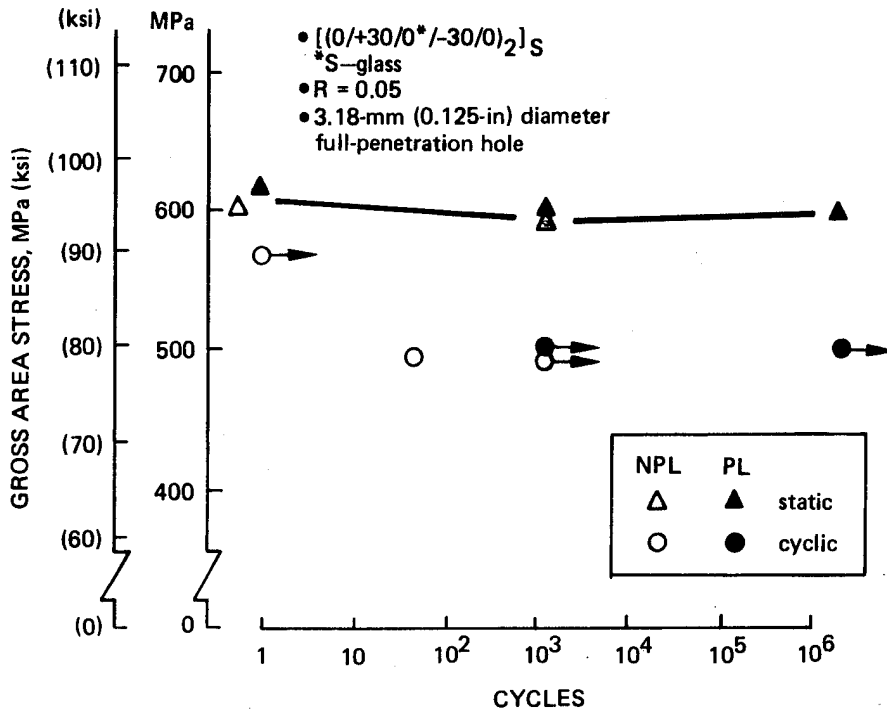


Figure 47. Fatigue Data for Laminate L3 1/8 FP Hole

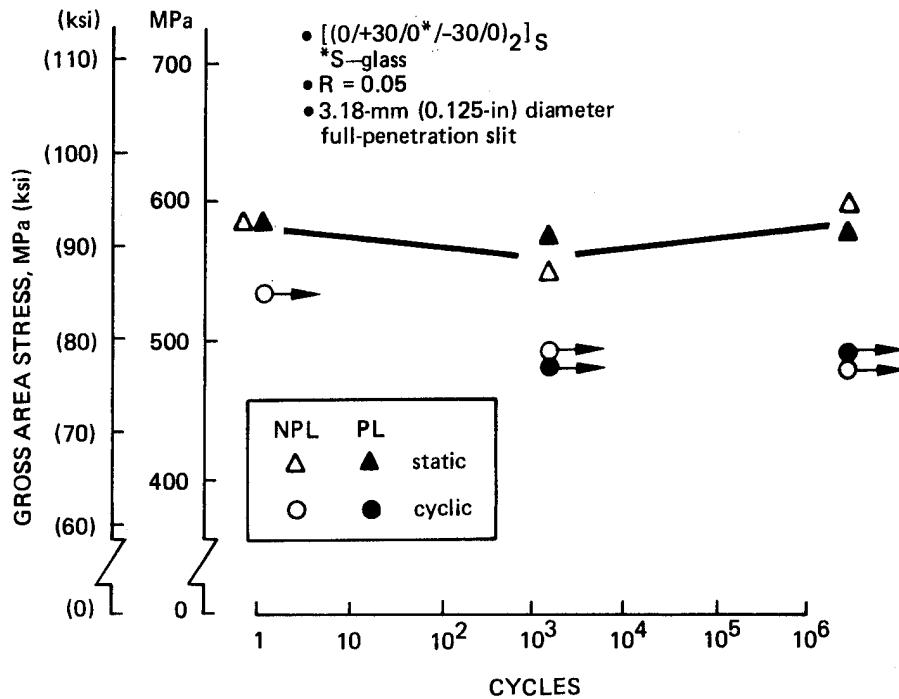


Figure 48. Fatigue Data for Laminate L3 1/8 FP Slit

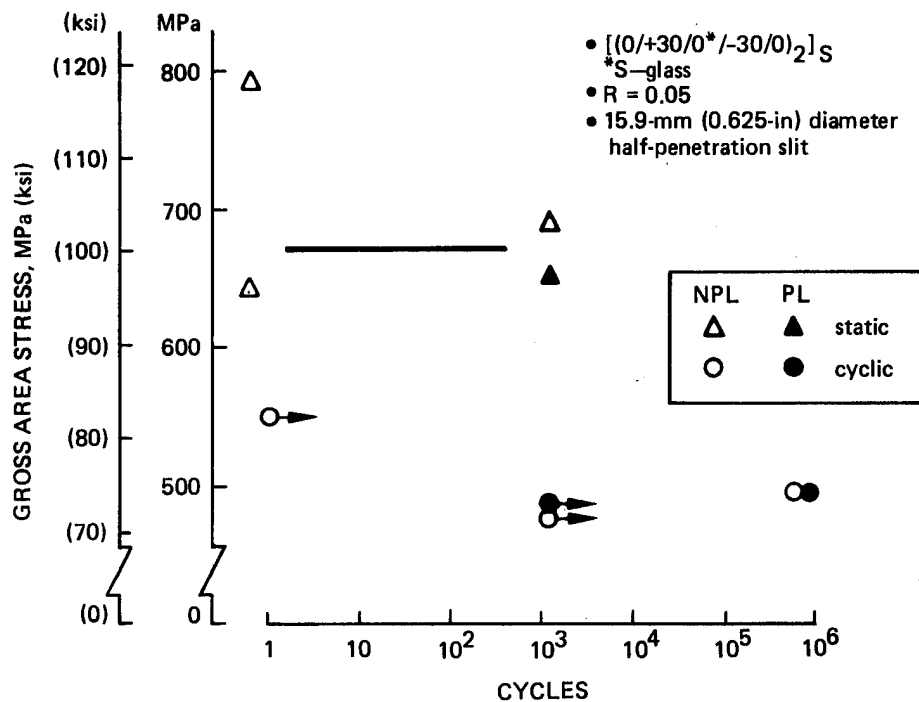


Figure 49. Fatigue Data for Laminate L3 5/8 HP Slit

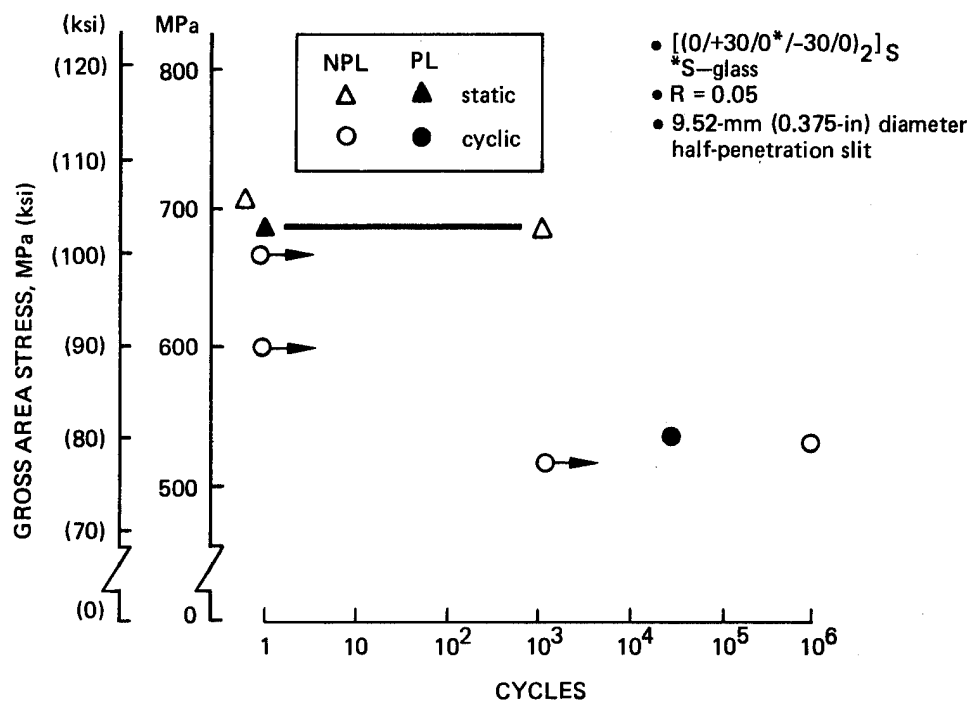


Figure 50. Fatigue Data for Laminate L3 3/8 HP Slit

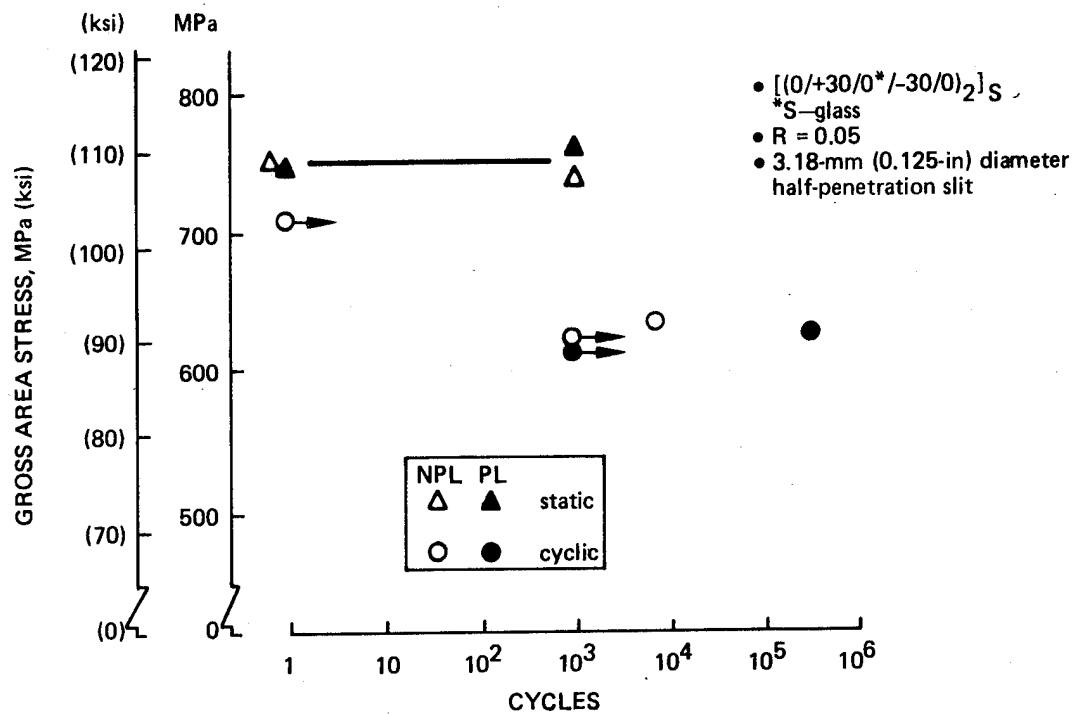


Figure 51. Fatigue Data for Laminate L3 1/8 HP Slit

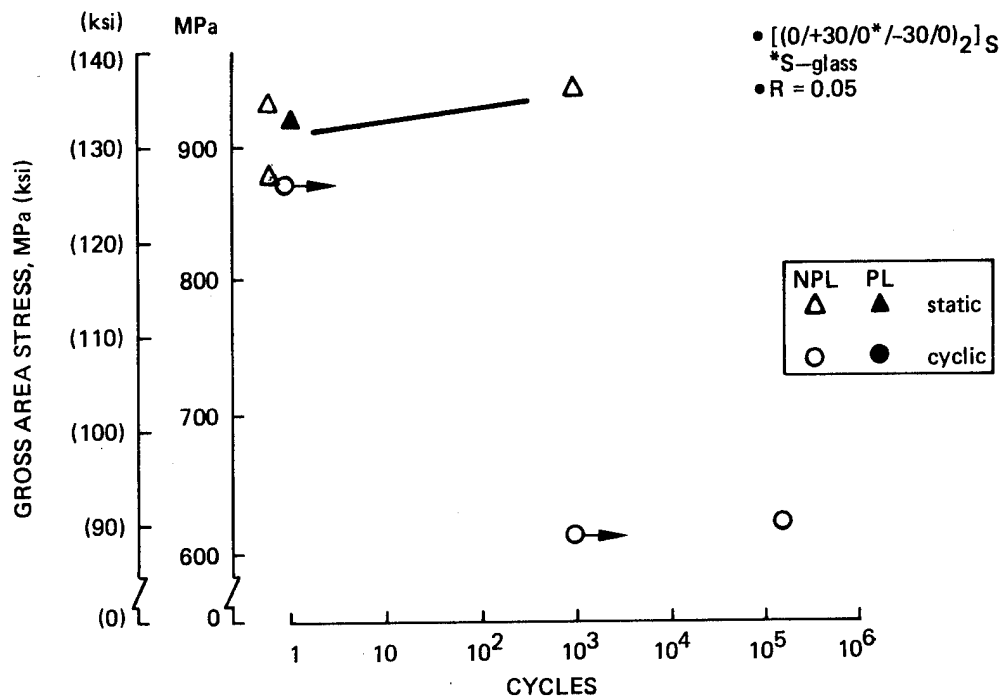


Figure 52. Fatigue Data for Laminate L3 With No Initial Defect

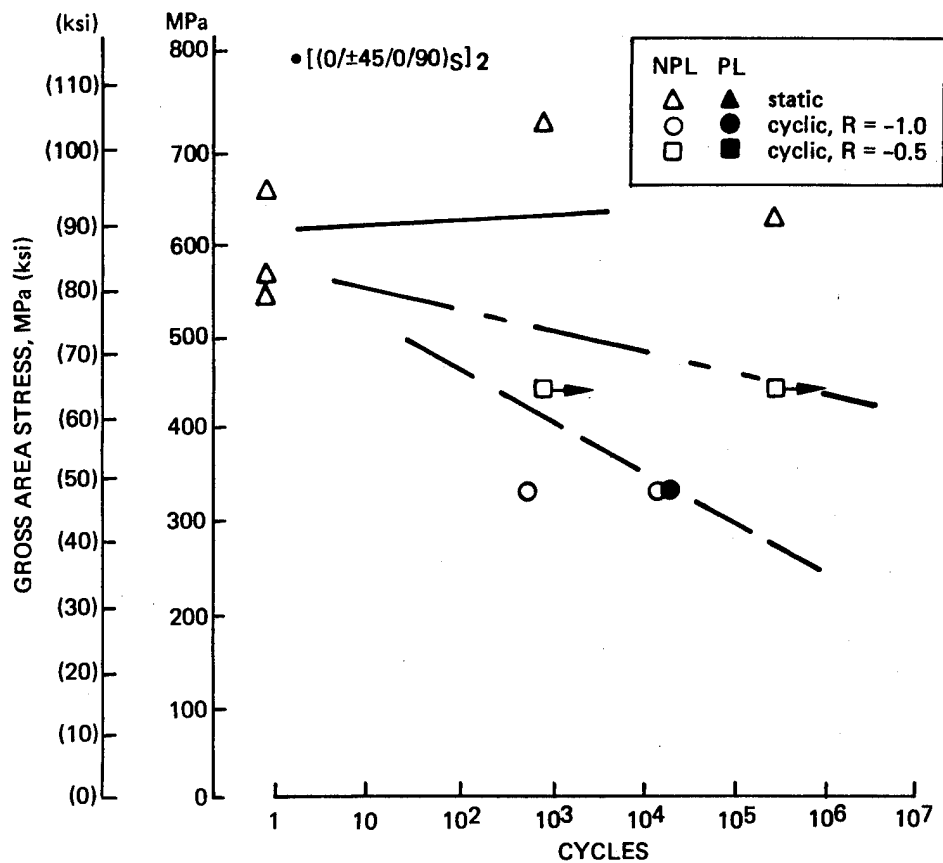


Figure 53. Tension Compression Fatigue Data for Laminate L1, No Initial Defect

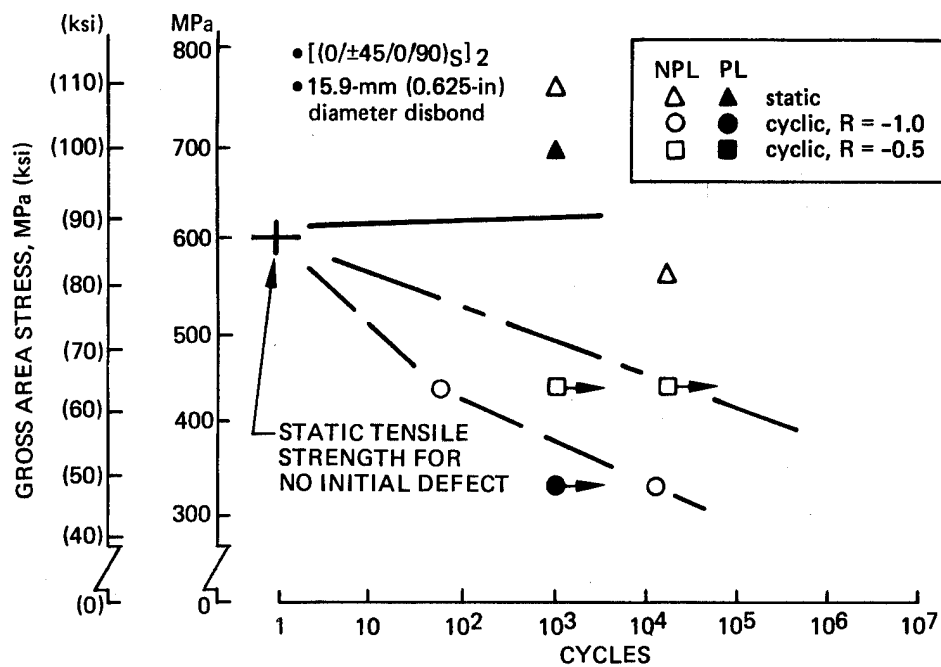


Figure 54. Tension Compression Fatigue Data for Laminate L1, Disbond Defect

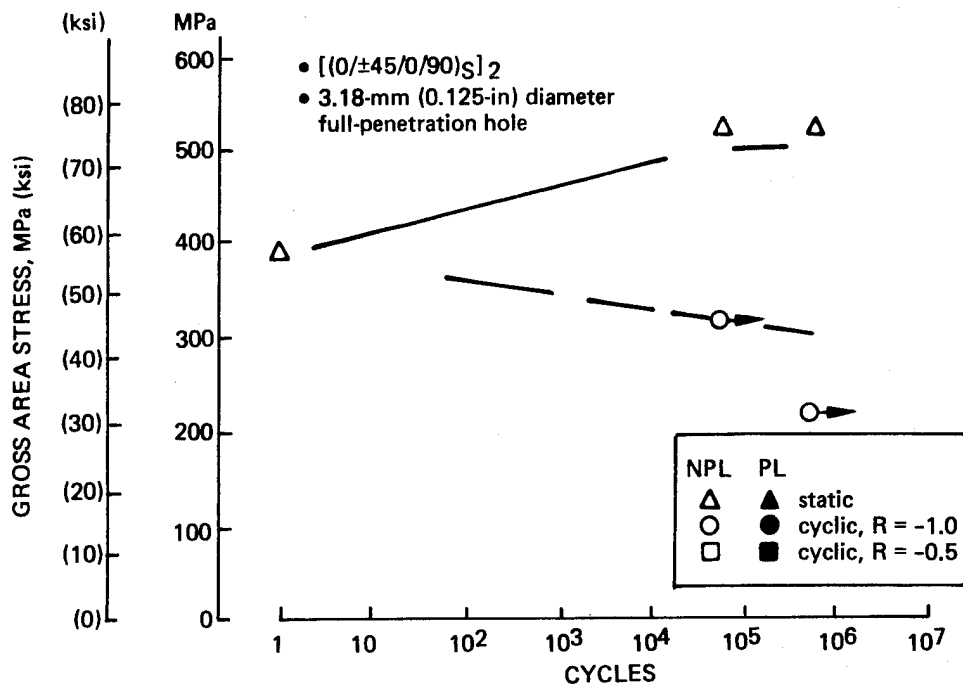


Figure 55. Tension Compression Fatigue Data for Laminate L1,1/8 FP Hole

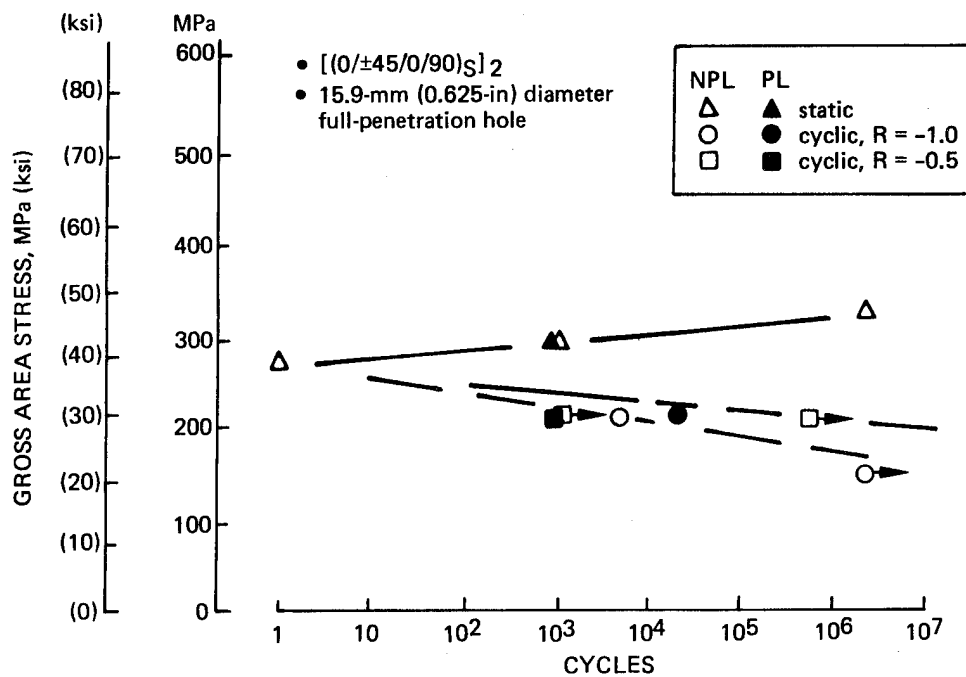


Figure 56. Tension Compression Fatigue Data for Laminate L1,5/8 FP Hole

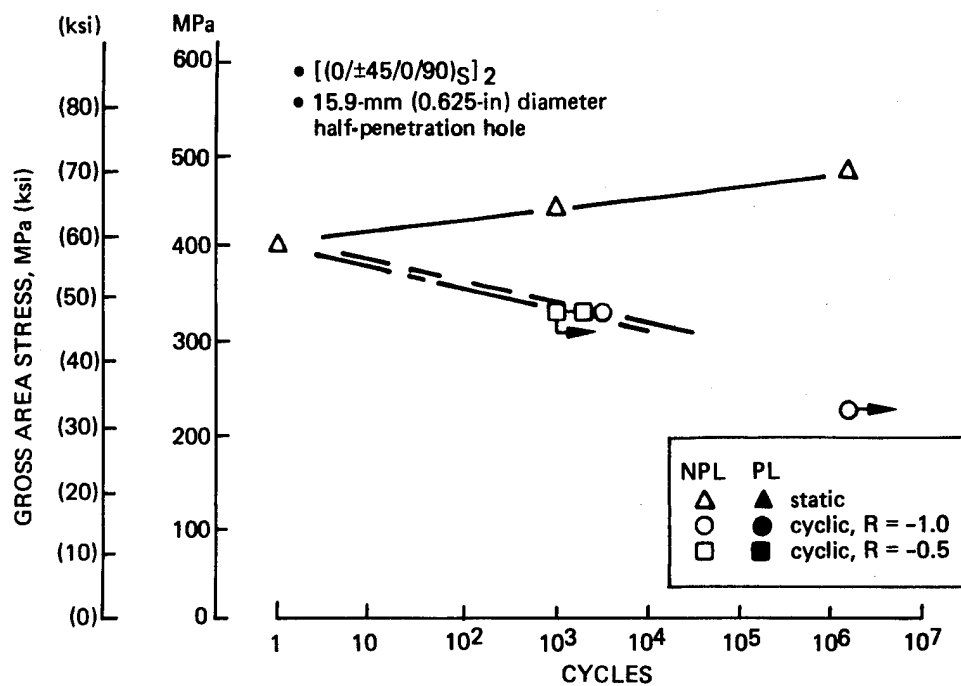


Figure 57. Tension Compression Fatigue Data for Laminate L1, 5/8 HP Hole

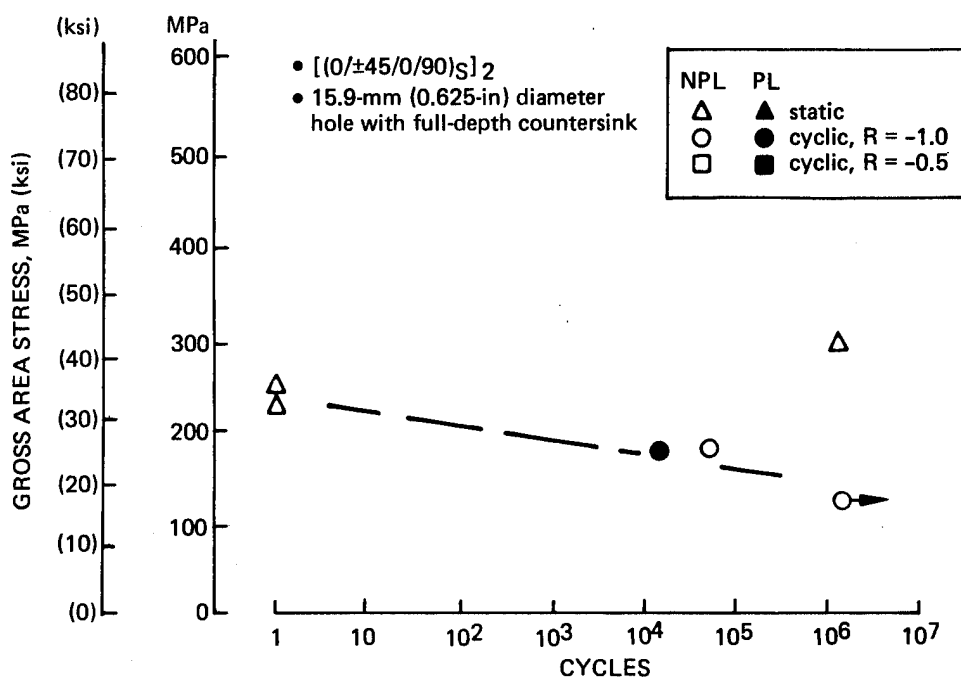


Figure 58. Tension Compression Fatigue Data for Laminate L1, 5/8 CSK Hole

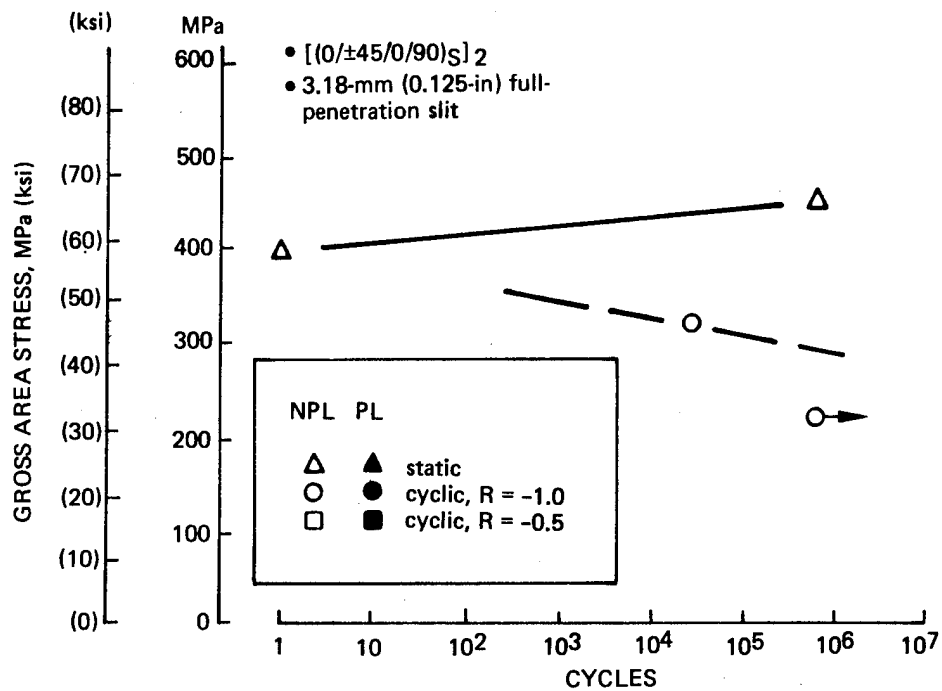


Figure 59. Tension Compression Fatigue Data for Laminate L1, 1/8 FP Slit

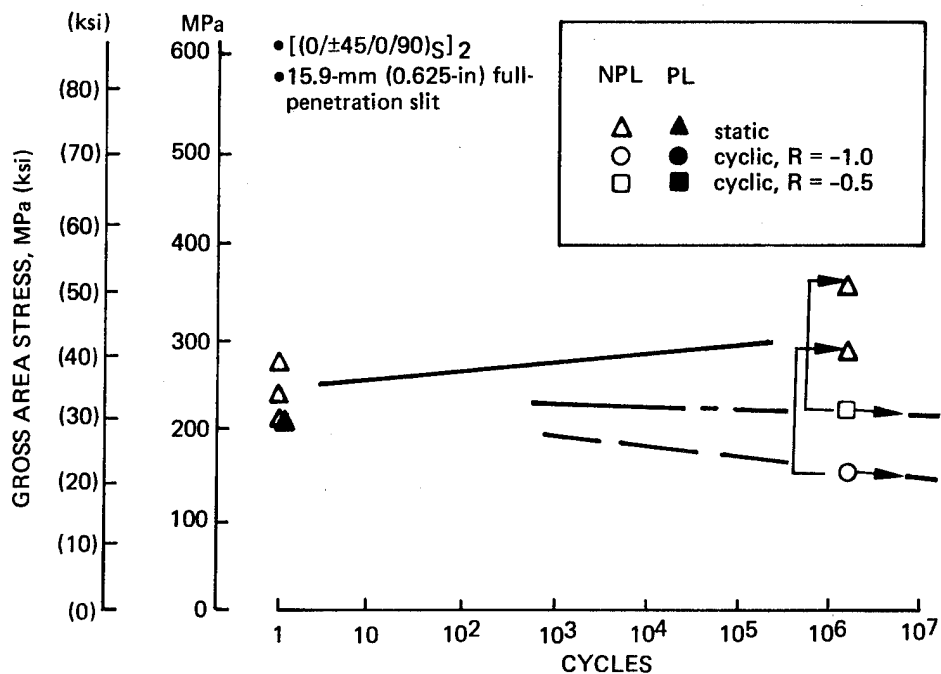


Figure 60. Tension Compression Fatigue Data for Laminate L1, 5/8 FP Slit

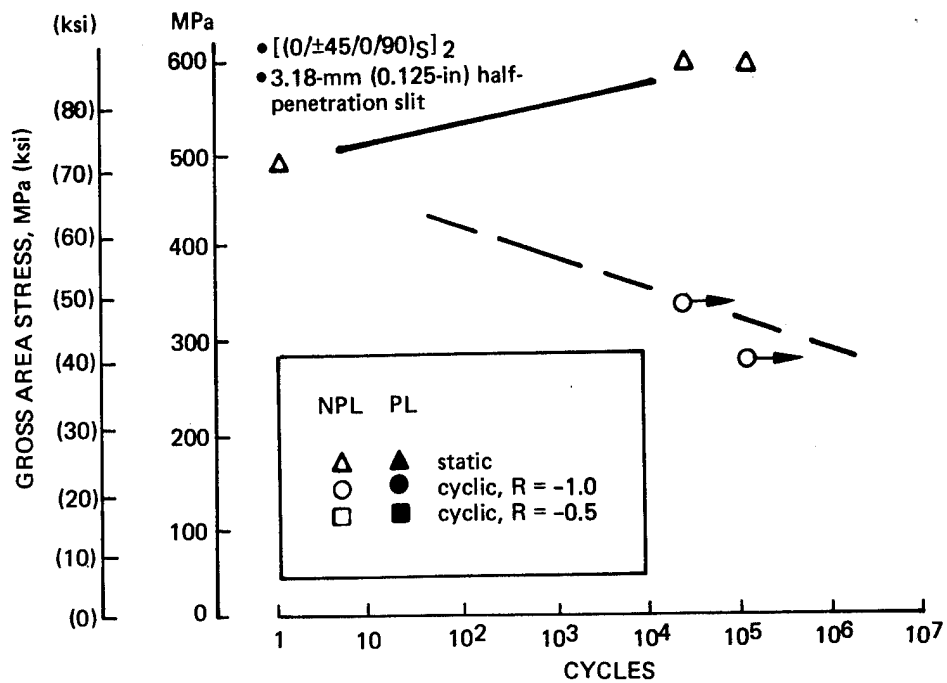


Figure 61. Tension Compression Fatigue Data for Laminate L1, 1/8 HP Slit

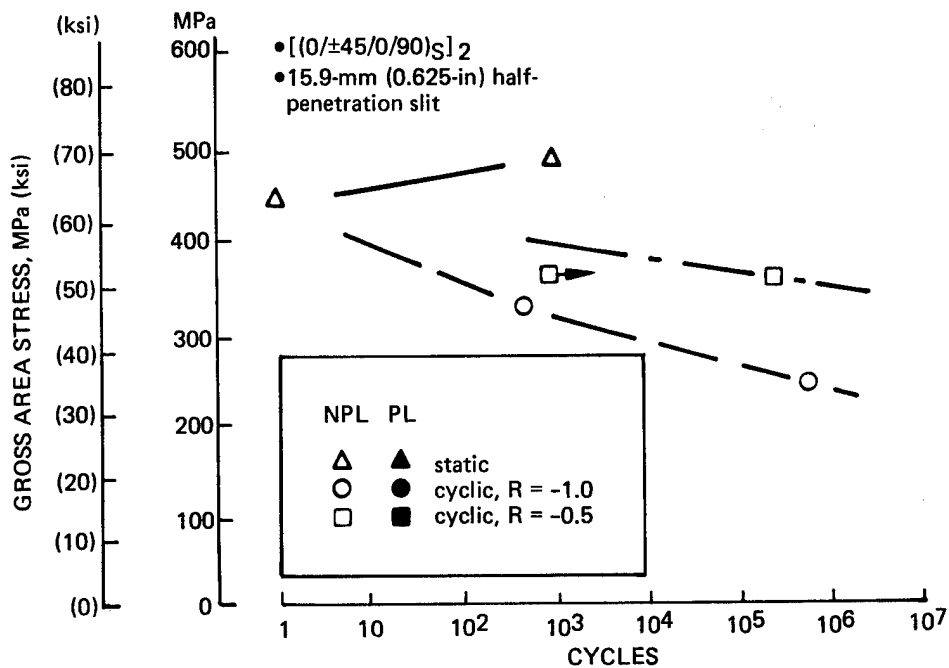


Figure 62. Tension Compression Fatigue Data for Laminate L1, 5/8 HP Slit

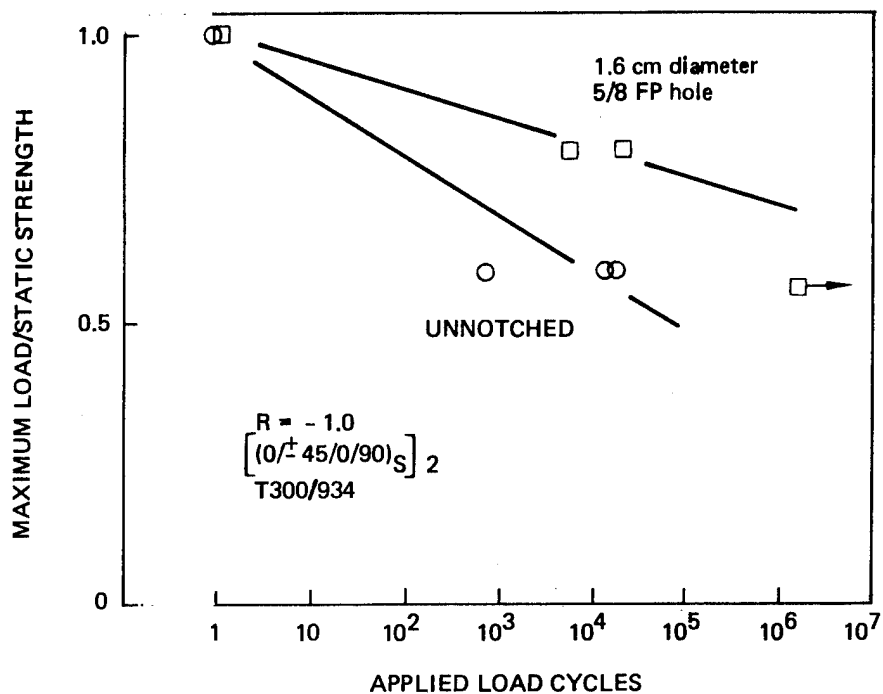


Figure 63. Relative Fatigue Behavior of Unnotched and Circular Hole Flawed Specimens

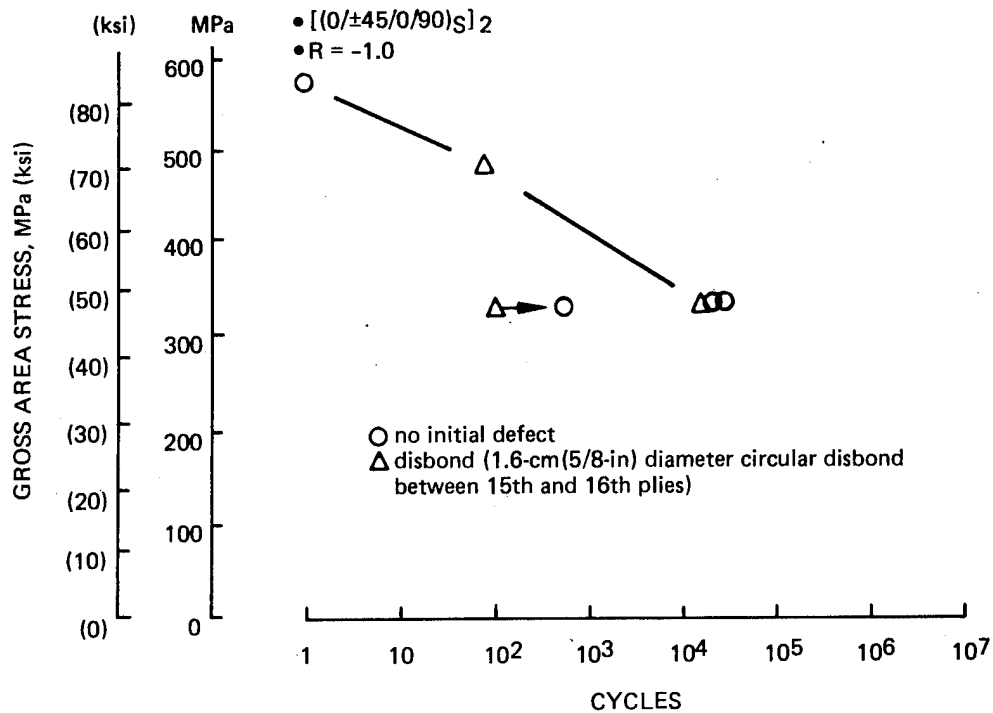


Figure 64. Comparison of Circular Disbond and No Initial Defects

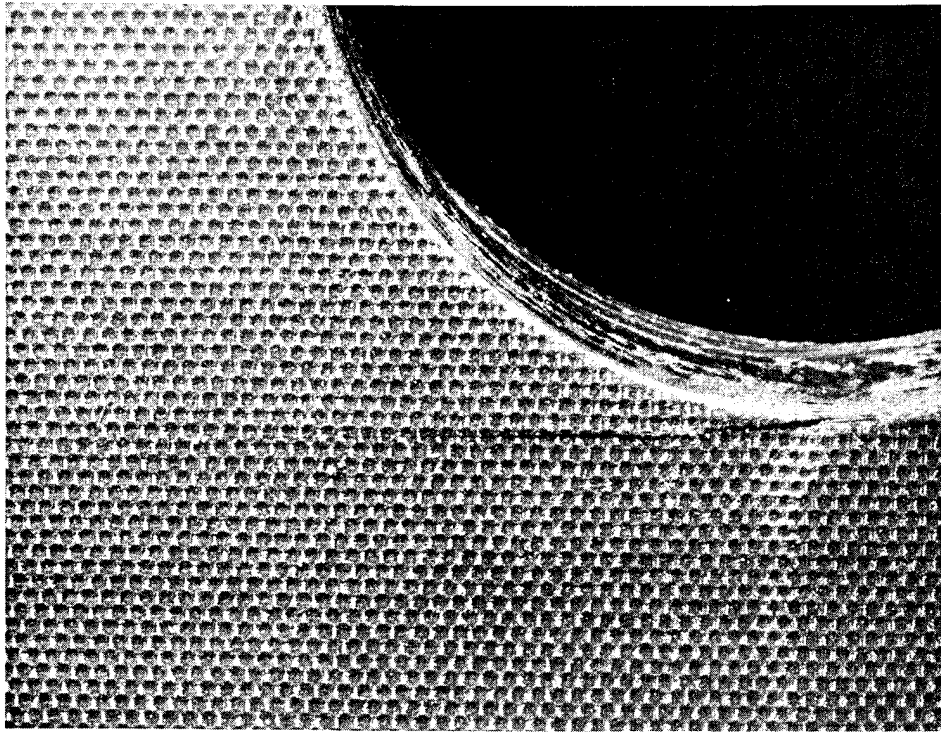


Figure 65. Laminate L2 Fatigue Test Specimen – 5/8 FP Hole, 10^3 Cycles

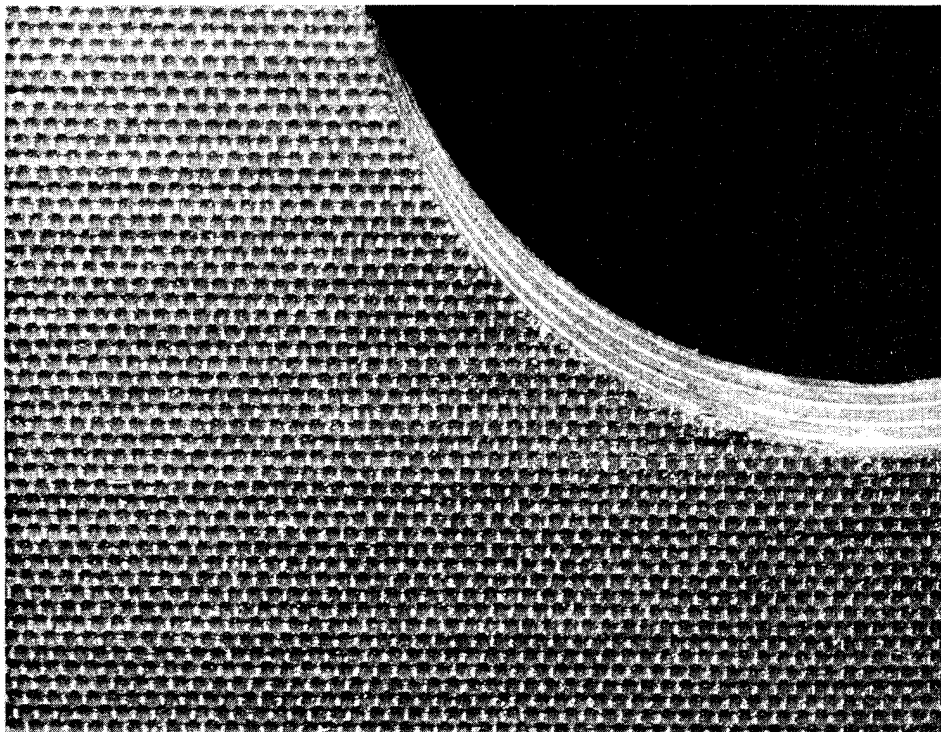
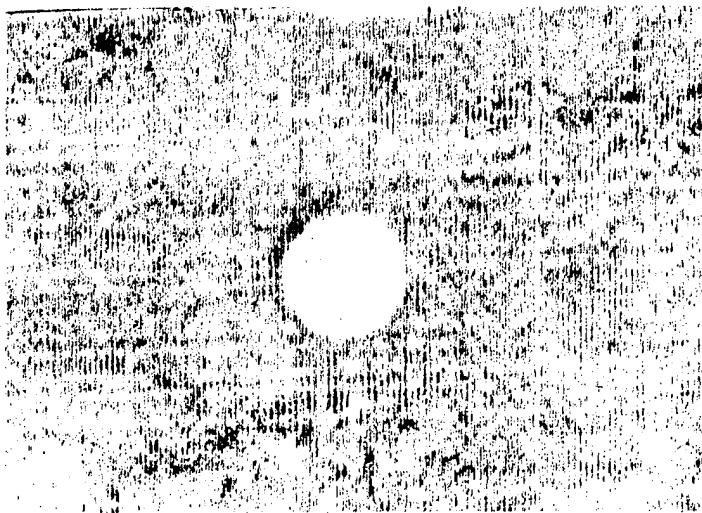
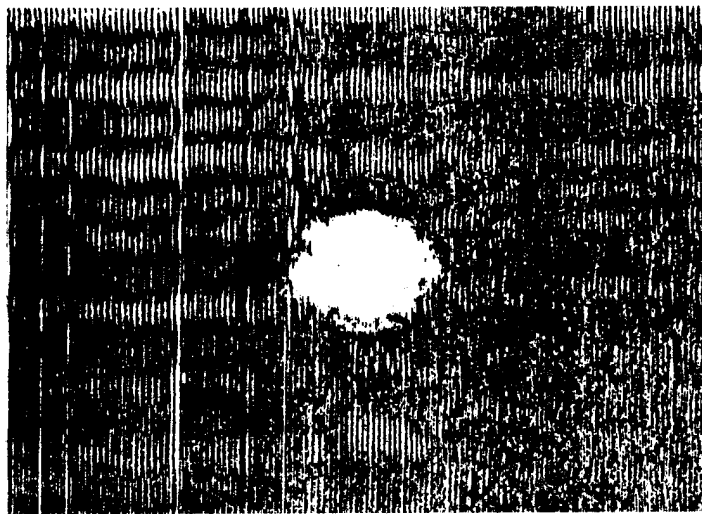


Figure 66. Laminate L3 Fatigue Test Specimen – 5/8 FP Hole, 1.5×10^6 Cycles

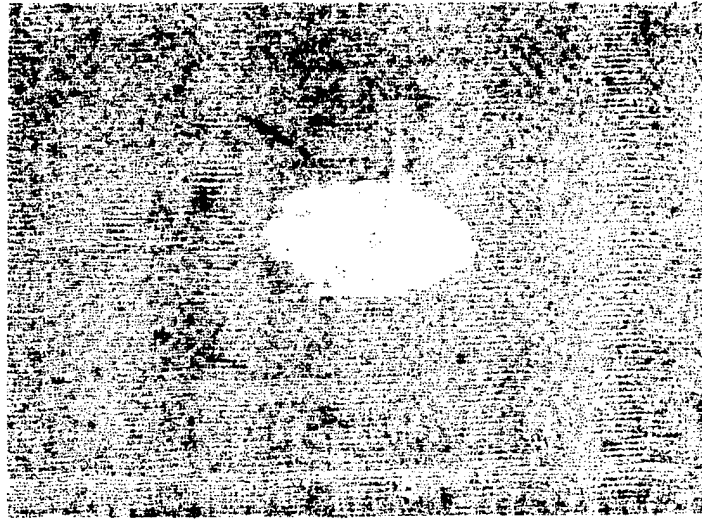
BEFORE TEST



AFTER PRELOAD



AFTER 10³ CYCLES

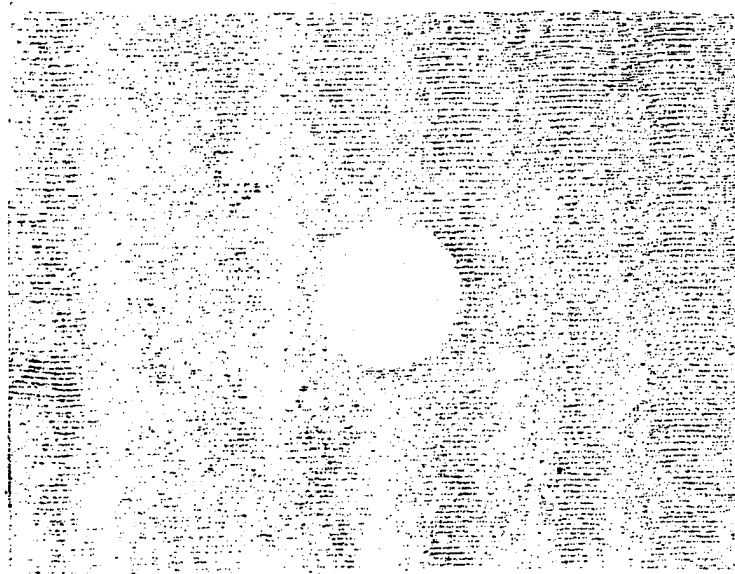


• Specimen L1-6-3

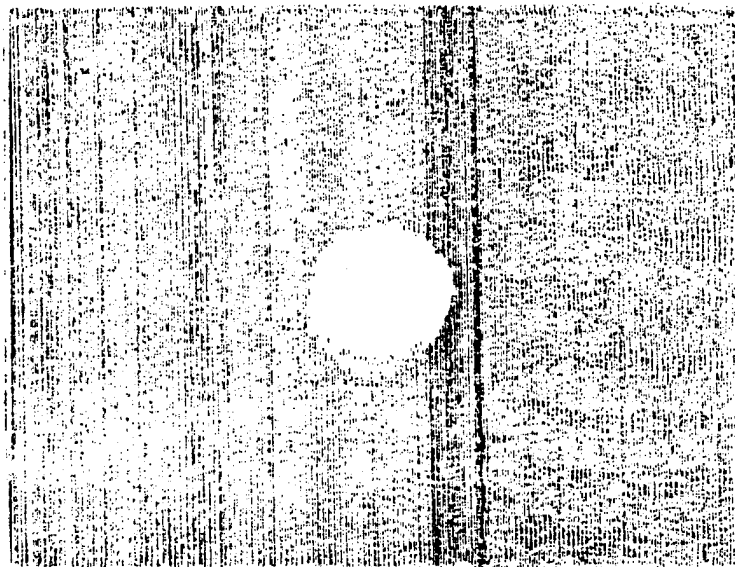
• 15.8-mm (0.625-in)-dia half-penetration hole

Figure 67. Ultrasonic Scan Records of Laminate L1 Specimen Containing 5/8 HP Hole

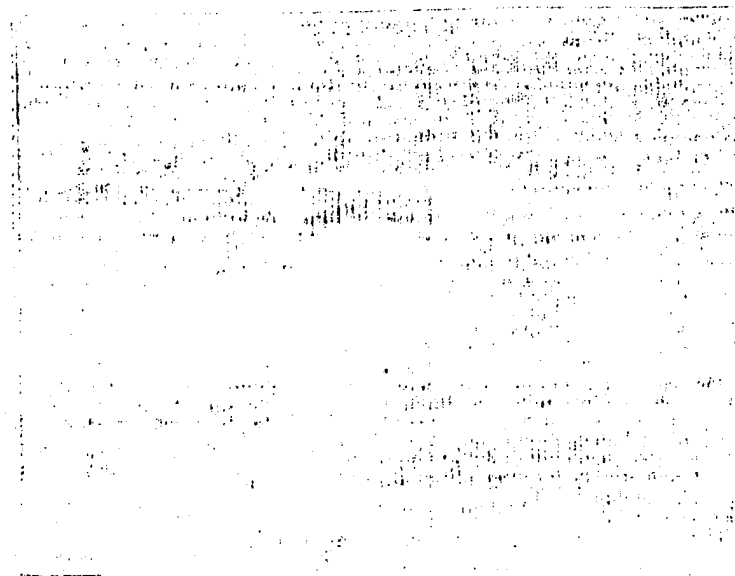
AFTER 10⁵ CYCLES



AFTER PRELOAD



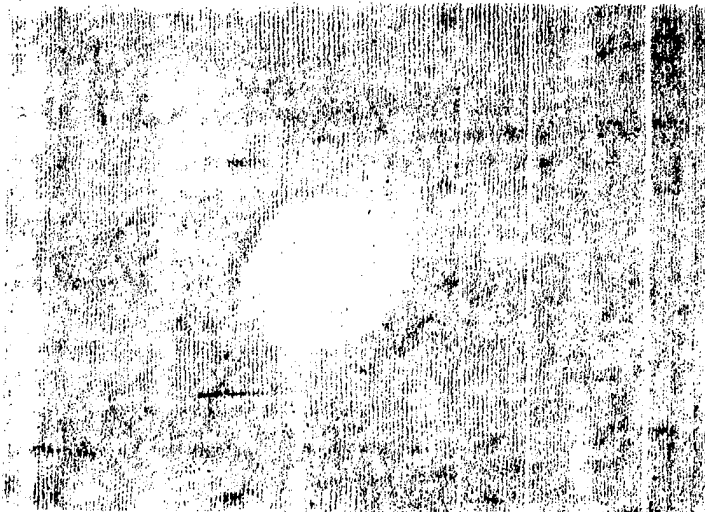
BEFORE TEST



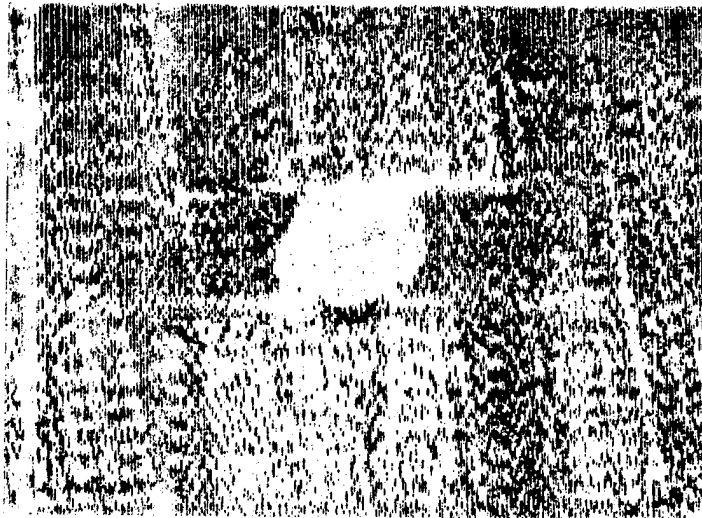
- Specimen L1-5-9
- 15.8-mm (0.625-in)-dia half-penetration hole

Figure 68. Ultrasonic Scan Records of Laminate L1 Specimen Containing 5/8 FP Hole

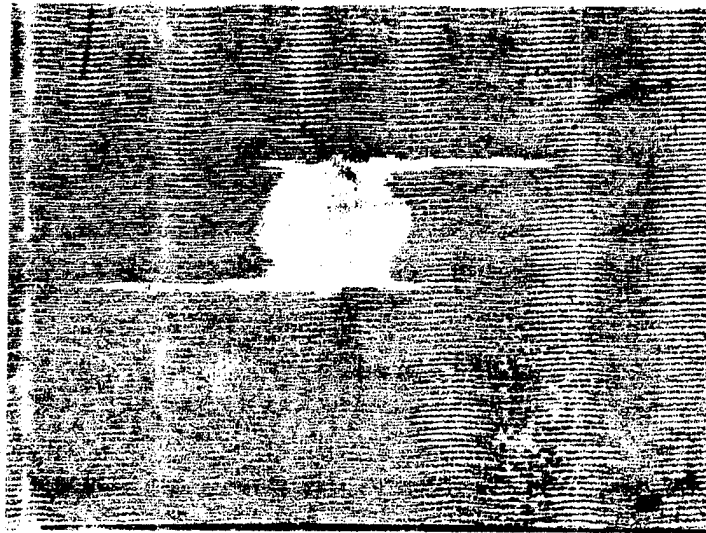
BEFORE TEST



AFTER PRELOAD



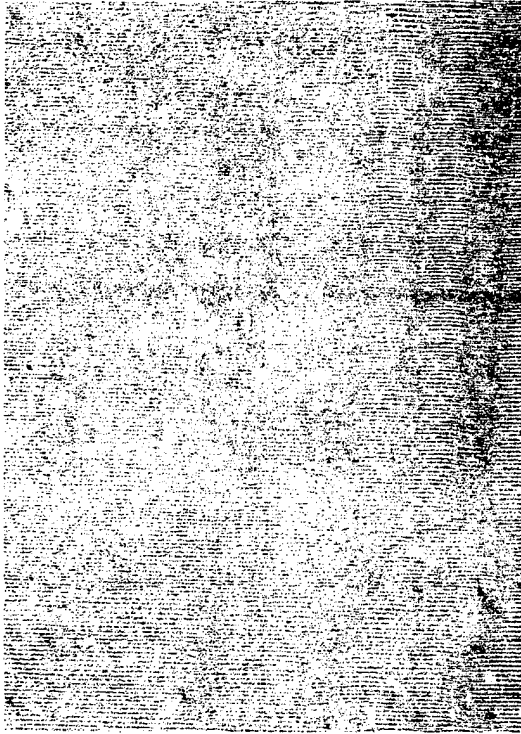
AFTER 10³ CYCLES



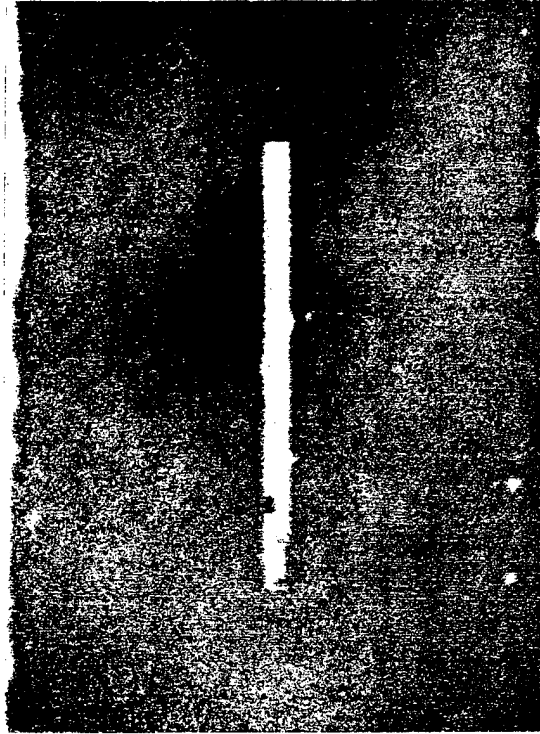
- Specimen L2-1-32
- 15.8-mm (0.625-in)-dia full-penetration hole

Figure 69. Ultrasonic Scan Records of Laminate L2 Specimen Containing 5/8 FP Hole

BEFORE TEST



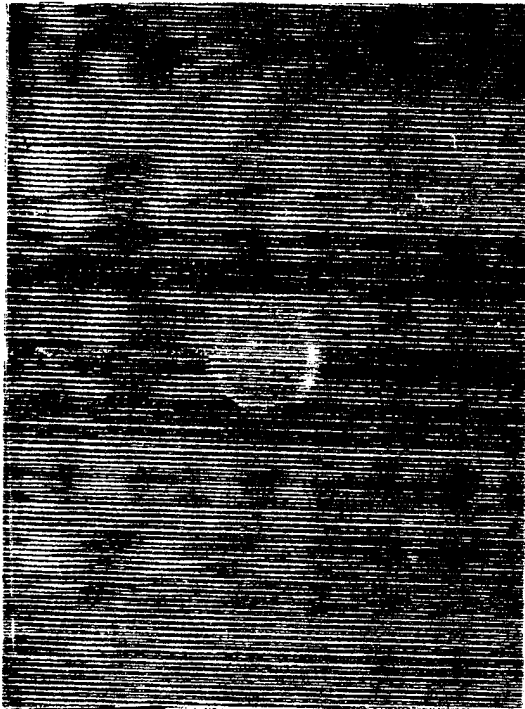
AFTER 114,600 CYCLES



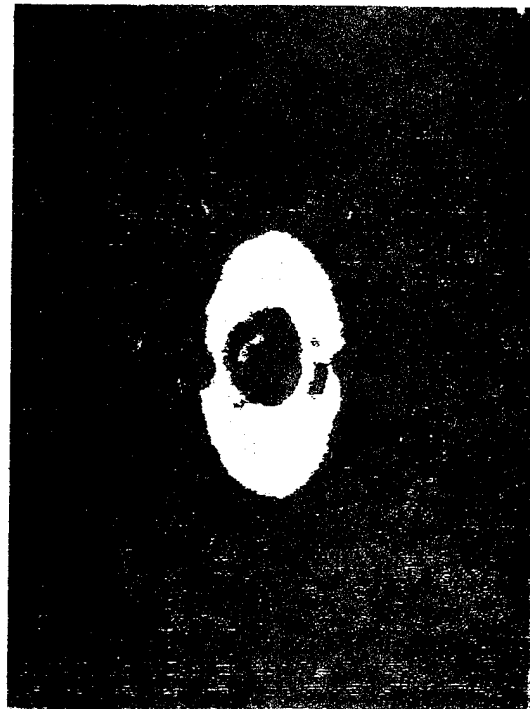
- Specimen L1-10-27
- 3.18 mm (0.125-in) half-penetration slit

Figure 70. Ultrasonic Scan Record for Laminate L1 Tension-Compression Fatigue Test Specimen 1/8 HP Slit

BEFORE TEST



AFTER 10^3 CYCLES



- Specimen L1-10-15
- 15.8-mm (0.625-in) half-penetration hole

Figure 71. Ultrasonic Scan Record for Laminate L1 Tension-Compression Fatigue Test Specimen 5/8 HP Hole

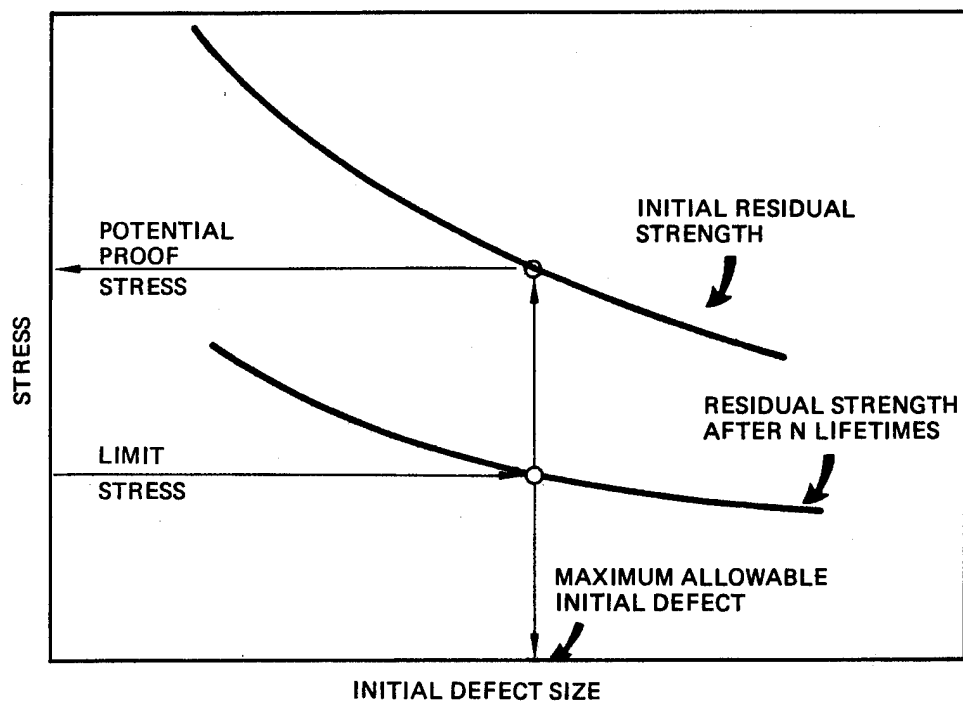


Figure 72. Potential Proof Test Method

LAMINATE L1 DEFECT TYPES

- No defect
- Half-penetration hole (HP hole)
- Full-penetration hole (FP hole)
- Half-penetration slit (HP slit)
- Full-penetration slit (FP slit)
- Countersink hole (CSK hole)

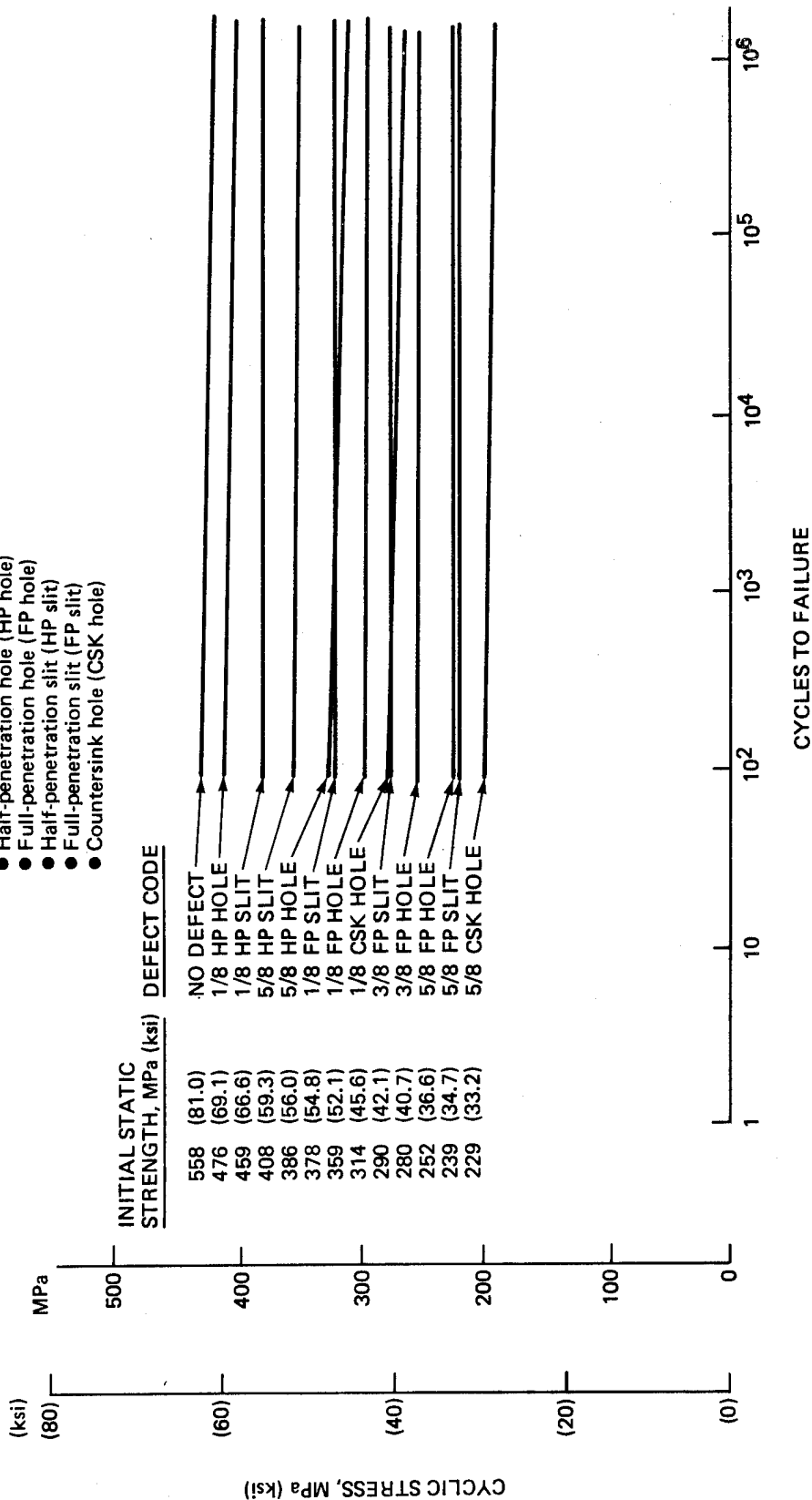


Figure 73. Minimum Fatigue Behavior for L1 Laminate Test Specimens Having Various Defects

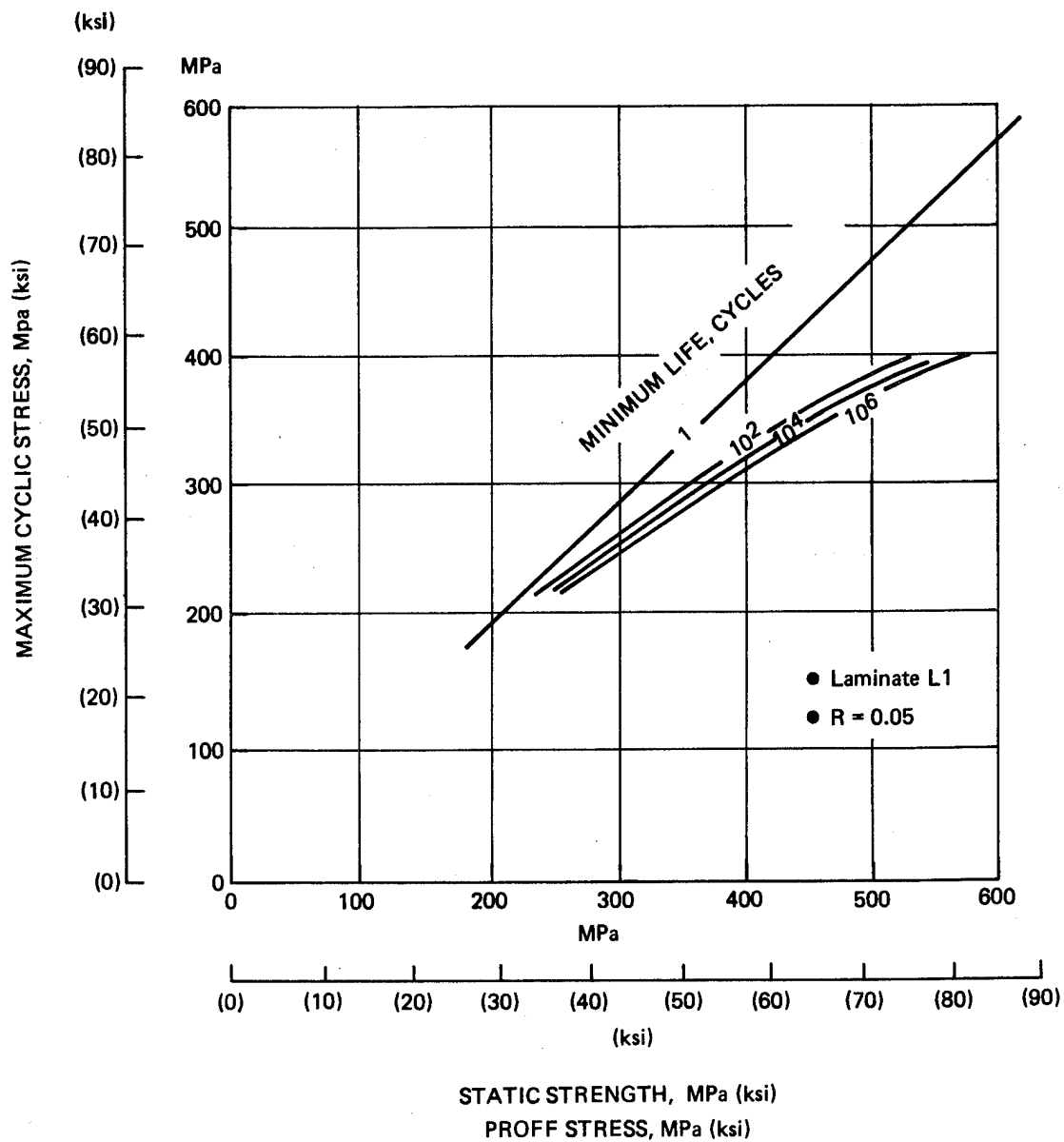


Figure 74. Proof Stress Requirements for Life Assurance of Laminate L1

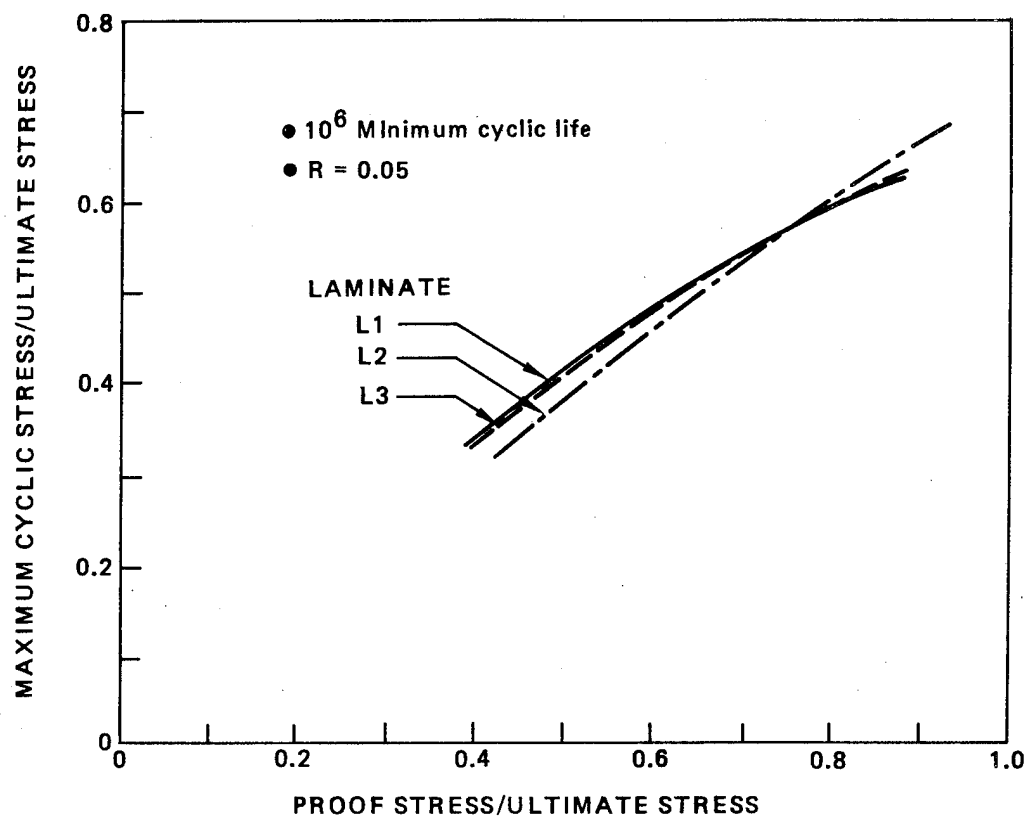


Figure 75. Comparison of Proof Stress Requirements of Tested Laminates
 at 10^6 Cyclic Life

APPENDIX A

STATIC AND CYCLIC TEST DATA

This appendix contains the static and cyclic test data for all specimens. The reported data include specimen geometry, loadings and test parameters. The gross section stresses have been reported for all the critical test conditions.

| SPEC. NO. | LAYUP | THICK-NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|----------------------------|-----------------------|----------------|-----------------------|----------------------|----------------------------|-------------------|--------------------------|--------------------|--------------------------------------|-----------------------|--|------|-----------------------|--------------------|---------------|--------------------------------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MN/m ² (KSI) |
| LI-1-11 | L1 | 3.05 (0.120) | 75.7 (2.981) | 5/8 FP N/A | 15.7 (0.62) | | - | STATIC | RT | 0 | - | NONE | - | - | - | 58,300 (13,100) | 252 (36.6) | |
| LI-1-12 | | 3.15 (0.124) | 75.9 (2.990) | | 15.8 (0.625) | | - | PRELOAD STATIC | | 52,600 (11,800) | 220 (31.9) | NONE | - | - | - | 42,200 (9,400) | 264 (38.3) | |
| LI-5-6 | | 3.25 (0.128) | 77.7 (3.059) | | 15.7 (0.620) | | - | CYCLIC | | 0 | - | 52,500 (11,800) | 207 (30.1) | 0.05 | 10 ³ | 68,000 (15,300) | 270 (39.1) | |
| LI-5-5 | | 3.15 (0.124) | 76.5 (3.011) | | 15.8 (0.624) | | - | | | 0 | - | 52,500 (11,800) | 216 (31.3) | | 10 ³ | 64,500 (14,500) | 265 (38.5) | |
| LI-5-4 | | 3.05 (0.120) | 75.6 (2.977) | | 15.8 (0.623) | | - | | | 0 | - | 46,600 (10,400) | 202 (29.3) | | 1.5 x 10 ⁴ | 68,400 (15,300) | 299 (43.4) | OVERLOAD CRACK TEST |
| LI-5-8 | | 3.05 (0.120) | 75.8 (2.984) | | 15.7 (0.621) | | - | PRELOAD CYCLIC | | 52,500 (11,810) | 218 (32.0) | - | - | | 1 | - | - | |
| LI-5-9 | | 3.15 (0.125) | 75.8 (2.984) | | 15.7 (0.62) | | - | | | 52,500 (11,810) | 218 (31.7) | 52,500 (11,800) | 218 (31.6) | | 10 ³ | 71,400 (16,050) | 296 (43.0) | |
| LI-5-7 | | 3.20 (0.126) | 75.4 (2.970) | | 15.8 (0.622) | | - | | | 52,500 (11,810) | 218 (31.6) | 46,600 (10,400) | 193 (28.0) | | 1.5 x 10 ⁴ | 77,700 (17,300) | 293 (42.5) | |
| LI-2-9 | L1 | 3.28 (0.129) | 76.0 (2.994) | 5/8 FP SHT. | 15.7 (0.62) | | - | STATIC | | 0 | - | NONE | - | - | - | 59,600 (13,400) | 239 (34.7) | |
| LI-2-10 | | 3.25 (0.128) | 75.5 (2.992) | | 16.0 (0.63) | | - | PRELOAD STATIC | | 53,600 (12,000) | 218 (31.7) | NONE | - | - | - | 42,300 (9,400) | 254 (36.8) | |
| LI-7-9 | | 3.25 (0.128) | 76.5 (3.012) | | 15.7 (0.62) | | - | CYCLIC | | 0 | - | 53,400 (12,000) | 214 (31.1) | 0.05 | 1.5 x 10 ⁴ | 68,300 (15,300) | 275 (39.9) | |
| LI-7-10 | | 3.22 (0.127) | 75.6 (2.977) | | 15.7 (0.62) | | - | | | 0 | - | 53,400 (12,000) | 218 (31.7) | | 10 ³ | 69,400 (15,600) | 285 (41.3) | |
| LI-7-11 | | 3.12 (0.123) | 76.4 (3.008) | | 16.0 (0.63) | | - | | | 0 | - | 53,400 (12,000) | 218 (32.4) | | 10 ³ | 63,600 (14,300) | 267 (38.7) | FAILURE |
| LI-7-12 | | 3.20 (0.126) | 75.9 (2.987) | | 15.7 (0.62) | | - | PRELOAD CYCLIC | | 53,600 (12,000) | 221 (32.0) | 53,400 (12,000) | 220 (31.9) | | 7 | - | - | FAILURE |
| LI-7-13 | | 3.18 (0.125) | 75.6 (2.977) | | 16.3 (0.64) | | - | | | 53,600 (12,000) | 223 (32.4) | 53,400 (12,000) | 222 (32.2) | | 2 | - | - | |
| LI-7-14 | | 3.22 (0.127) | 75.8 (2.986) | | 15.2 (0.60) | | - | | | 53,600 (12,000) | 219 (31.8) | 53,400 (12,000) | 218 (31.6) | | 1.5 x 10 ⁴ | 67,400 (15,200) | 276 (40.1) | |

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LAMINATE L1 (0/145/0/40)372
 GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|--------------------------------|-----------------------|----------------|-----------------------|----------------------|----------------------------|-------------------|--------------------------|--------------------|--------------------------------------|--------------------------|---|-----|-----------------------|--------------------|---------------|--------------------------------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MN/m ² (KSI) |
| L1-1-7 | L1 | 3.07 (.121) | 75.8 (2.984) | 3/8 FP HOLE | 9.4 (.37) | | | STATIC | RT | 0 | - | NONE | - | - | 65,400 (14,700) | 281 (40.1) | | |
| L1-1-8 | | 3.18 (.125) | 75.6 (2.975) | | 9.4 (.37) | | | PRELOAD STATIC | | 58,500 (13,150) | 244 (35.4) | NONE | - | - | 72,900 (16,400) | 304 (44.4) | | |
| L1-4-11 | | 3.22 (.127) | 76.1 (2.996) | | 9.5 (.375) | | | CYCLIC | | 0 | - | 58,900 (13,250) | 240 (34.2) | .05 | 10 ³ | 77,810 (17,500) | 317 (46.0) | |
| L1-4-12 | | 3.12 (.123) | 77.3 (3.042) | | 9.4 (.375) | | | | | 0 | - | 58,900 (13,250) | 244 (35.4) | | 10 ⁶ , 320 | 79,700 (17,700) | 316 (47.3) | |
| L1-5-1 | | 3.07 (.121) | 76.4 (3.004) | | 9.4 (.375) | | | | | 0 | - | 58,900 (13,250) | 251 (36.4) | | 1.5 x 10 ⁶ | 83,200 (18,700) | 354 (51.4) | |
| L1-9-1 | | 3.05 (.120) | 75.0 (2.953) | | 9.4 (.375) | | | PRELOAD CYCLIC | | 58,700 (13,250) | 258 (37.4) | 58,900 (13,250) | 258 (37.4) | | 10 ³ | 72,900 (16,400) | 319 (46.3) | |
| L1-5-3 | | 3.18 (.125) | 75.9 (2.987) | | 9.4 (.375) | | | | | 58,700 (13,250) | 245 (35.5) | 58,900 (13,250) | 245 (35.5) | | 10 ⁵ | 77,810 (17,500) | 323 (46.9) | |
| L1-5-2 | | 3.18 (.125) | 75.9 (2.987) | | 9.5 (.375) | | | | | 58,700 (13,250) | 245 (35.5) | 58,900 (13,250) | 245 (35.5) | Y | 1.5 x 10 ⁶ | 83,400 (19,200) | 354 (51.4) | |
| L1-1-1 | | 3.25 (.128) | 75.4 (2.970) | 3/8 FP SLIT | 9.1 (.36) | | | STATIC | | 0 | - | NONE | - | - | 71,200 (16,000) | 290 (42.1) | | |
| L1-2-3 | | 3.16 (.124) | 76.0 (2.991) | | 9.4 (.37) | | | PRELOAD STATIC | | 64,100 (14,400) | 265 (38.5) | NONE | - | - | 71,600 (16,100) | 297 (43.1) | | |
| L1-7-4 | | 3.25 (.128) | 76.5 (3.012) | | 9.4 (.37) | | | CYCLIC | | 0 | - | 64,100 (14,400) | 257 (37.3) | .05 | 10 ³ | 74,300 (16,700) | 294 (43.3) | |
| L1-7-5 | | 3.25 (.128) | 76.4 (3.004) | | 9.4 (.37) | | | | | 0 | - | 64,100 (14,400) | 258 (37.4) | | 10 ⁵ | 83,200 (18,700) | 335 (48.6) | |
| L1-7-6 | | 3.19 (.124) | 76.3 (3.003) | | 9.4 (.37) | | | | | 0 | - | 60,900 (13,700) | 251 (36.4) | | 1.5 x 10 ⁶ | 82,700 (18,600) | 345 (50.0) | |
| L1-7-8 | | 3.22 (.127) | 76.0 (2.992) | | 9.4 (.37) | | | PRELOAD CYCLIC | | 64,100 (14,400) | 261 (37.9) | 64,100 (14,400) | 261 (37.9) | | 10 ³ | 80,100 (18,000) | 327 (47.4) | |
| L1-7-7 | | 3.10 (.122) | 75.8 (2.98) | | 9.4 (.37) | | | | | 61,100 (14,400) | 272 (39.5) | 64,100 (14,400) | 272 (39.5) | | 10 ⁵ | 80,100 (18,000) | 341 (49.4) | |
| L1-9-2 | | 3.05 (.120) | 76.0 (2.954) | | 13.7 (.54) | | | | | 64,100 (14,400) | 280 (40.6) | 60,900 (13,700) | 266 (38.6) | | 1.5 x 10 ⁶ | 83,200 (18,700) | 363 (52.7) | |

1) LAMINATE LI [C(0/±45/0/90)]₂

2) GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|--------------------------------|-----------------------|----------------|-----------------------|----------------------|-------------------------------|--------------|-----------------------------|-------------------|--------------------------------------|--------------------------|---|---|--------------------|-------------------|---------------|--|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MN/m ² (KSI) |
| L1-1-3 | L1 | 3.12 (.123) | 76.1 (2.995) | 1/8 FP HOLE | 3.0 (.12) | | - | STATIC | RT | 0 | - | NONE | - | - | - | 85400 (19200) | 359 (52.1) | CALC. AREA FAILURE |

LAMINATE L1 [0/45/0/90]sJ2

GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | | RESIDUAL STATIC | | REMARKS |
|-----------|-------|--------------------------------|-----------------------|----------------|-----------------------|----------------------|----------------------------|-----------|--------------------------|-------------------|--------------------------------------|--------------------------|---|------|-----------------------|--------------------|--------------------------------------|--|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | STRESS MN/m ² (KSI) | |
| L1-1-13 | L1 | 3.07 (.121) | 75.7 (2.980) | S/B HP NOLE | 15.7 (.62) | 0 | 1.5 (0.06) | STATIC | RT | 0 | - | NONE | - | - | - | 84800 (20200) | 386 (56.0) | |
| L1-1-14 | | 3.10 (.122) | 75.4 (2.970) | | 15.7 (.62) | | | PRELOAD | | 80900 (18200) | 346 (50.2) | NONE | - | - | - | 82300 (19400) | 369 (53.5) | |
| L1-5-10 | | 3.18 (.125) | 76.4 (3.008) | | 15.7 (.62) | | | CYCLIC | | 0 | - | 72900 (16400) | 201 (29.1) | -0.5 | 1502000 | 0 | 394 (57.2) | CYCLIC FAILURE AT CALL TEST TERMINATION |
| L1-5-11 | | 3.20 (.126) | 76.5 (3.010) | | 15.7 (.62) | | | | | 0 | - | 72900 (16400) | 201 (29.1) | | 10 ⁵ | - | - | |
| L1-5-12 | | 3.12 (.123) | 74.4 (2.928) | | 15.7 (.62) | | | | | 0 | - | 72900 (16400) | 201 (29.1) | | 10 ³ | 82600 (18800) | 354 (51.2) | |
| L1-6-1 | | 3.07 (.121) | 75.9 (2.986) | | 15.7 (.62) | | | PRELOAD | | 80900 (18200) | 347 (50.3) | 72900 (16400) | 201 (29.1) | | 6 | - | - | FATIGUE FAILURE |
| L1-6-2 | | 3.18 (.125) | 75.4 (2.971) | | 15.7 (.62) | | | CYCLIC | | 80900 (18200) | 327 (47.1) | 72900 (16400) | 201 (29.1) | | 1550000 | 0 | 402 (58.3) | |
| L1-6-3 | | 3.15 (.124) | 75.9 (2.969) | | 15.7 (.62) | | | | | 80900 (18200) | 338 (49.1) | 72900 (16400) | 201 (29.1) | | 10 ³ | 84800 (19400) | 354 (51.2) | |
| L1-2-11 | | 3.18 (.125) | 76.1 (2.994) | S/B HP SALT | 15.7 (.62) | | 1.5 (0.06) | STATIC | | 0 | - | NONE | - | | - | 98800 (22200) | 409 (59.3) | |
| L1-2-12 | | 3.10 (.122) | 76.4 (3.010) | | 16.2 (.64) | | | PRELOAD | | 84800 (20200) | 376 (54.5) | NONE | - | | - | 103000 (23300) | 437 (63.4) | |
| L1-8-1 | | 3.00 (.118) | 77.0 (3.030) | | 15.2 (.59) | | | STATIC | | 0 | - | 84800 (19000) | 247 (35.7) | -0.5 | 1504000 | 0 | 461 (66.8) | |
| L1-8-2 | | 3.12 (.123) | 76.4 (3.014) | | 14.5 (.57) | | | CYCLIC | | 0 | - | 84800 (19000) | 247 (35.7) | | 101410 | 102400 (23100) | 430 (62.2) | |
| L1-8-3 | | 3.10 (.122) | 76.4 (3.018) | | 14.5 (.57) | | | | | 0 | - | 84800 (19000) | 247 (35.7) | | 10 ³ | 102400 (23100) | 430 (62.2) | |
| L1-8-4 | | 3.18 (.125) | 75.9 (2.987) | | 14.0 (.55) | | | PRELOAD | | 84800 (20200) | 364 (52.6) | 84800 (19000) | 332 (48.2) | | 1.5 x 10 ⁶ | 104500 (23500) | 434 (62.9) | |
| L1-8-5 | | 3.12 (.123) | 76.7 (2.998) | | 15.0 (.59) | | | CYCLIC | | 84800 (20200) | 376 (54.6) | 84800 (19000) | 332 (48.2) | | 10 ⁵ | 104500 (23500) | 434 (62.9) | |
| L1-8-6 | | 3.10 (.122) | 75.8 (2.985) | | 14.8 (.58) | | | | | 84800 (20200) | 378 (54.9) | 84800 (19000) | 332 (48.2) | | 10 ³ | 97600 (22000) | 416 (60.4) | |

L1 LAMINATE SECTION
B CROSS SECTION

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|--------------------------------|-----------------------|-------------|-----------------------|----------------------|----------------------------|----------------|--------------------------|---------------------|--------------------------------------|-----------------------|--|-----|-----------------------|---------------------|---------------|---|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MN/m ² (KSI) |
| L1-1-5 | L1-D | 3.18 (.125) | 76.5 (3.011) | 1/8 HP HOLE | 3.0 (.12) | 0 | 1.5 (.06) | STATIC PRELOAD | RT | 0 | - | NONE | - | - | - | 115 700 (26 000) | 476 (.191) | TEARING START AT 14 200 CYCLES FATIGUE FAILURE |
| L1-1-6 | | 3.15 (.124) | 76.3 (3.002) | | 3.0 (.12) | | | STATIC | | 104 000 (23 400) | 434 (.162) | NONE | - | - | - | 109 400 (24 700) | 458 (.164) | |
| L1-4-5 | | 3.15 (.124) | 75.9 (2.978) | | 3.0 (.12) | | | CYCUL | | 0 | - | 93 800 (21 000) | 384 (.143) | .05 | 1.5 x 10 ⁶ | 112 000 (25 000) | 478 (.183) | |
| L1-4-6 | | 3.25 (.128) | 76.3 (3.003) | | 3.0 (.12) | | | | | 0 | - | 93 800 (21 000) | 378 (.143) | | 10 ⁵ | 120 100 (27 000) | 484 (.183) | |
| L1-4-7 | | 3.20 (.126) | 75.8 (2.983) | | 3.0 (.12) | | | | | 0 | - | 93 800 (21 000) | 387 (.147) | | 10 ⁵ | 120 300 (27 100) | 494 (.183) | |
| L1-4-8 | | 3.22 (.127) | 75.7 (2.982) | | 3.0 (.12) | | | PRELOAD | | 104 000 (23 400) | 426 (.164) | 93 800 (21 000) | 384 (.147) | | 1.5 x 10 ⁶ | 118 300 (26 400) | 484 (.183) | |
| L1-4-9 | | 3.10 (.122) | 75.7 (2.979) | | 3.0 (.12) | | | CYCUL | | 104 000 (23 400) | 444 (.171) | 93 800 (21 000) | 400 (.157) | | 32 515 | - | - | |
| L1-4-10 | | 3.18 (.125) | 75.3 (2.963) | | 3.0 (.12) | | | | | 104 000 (23 400) | 436 (.168) | 93 800 (21 000) | 393 (.151) | | 10 ⁵ | 104 100 (23 400) | 436 (.168) | |
| L1-2-3 | | 2.15 (.085) | 75.9 (2.991) | 1/8 HP SLIT | 3.3 (.13) | | 1.5 (.06) | STATIC | | 0 | - | NONE | - | - | - | 106 300 (23 600) | 459 (.177) | |
| L1-2-4 | | 2.80 (.110) | 75.4 (2.969) | | 3.3 (.13) | | | PRELOAD | | 15 800 (3 550) | 285 (.112) | NONE | - | - | - | 122 800 (27 600) | 496 (.183) | |
| L1-6-10 | | 3.00 (.118) | 75.9 (2.989) | | 3.0 (.12) | | | CYCUL | | 0 | - | 86 300 (19 400) | 379 (.149) | .05 | 1 500 400 | 135 200 (30 400) | 594 (.222) | |
| L1-6-11 | | 3.12 (.123) | 76.5 (3.011) | | 3.0 (.12) | | | | | 0 | - | 86 300 (19 400) | 361 (.141) | | 10 ⁵ | 122 800 (27 600) | 514 (.191) | |
| L1-6-12 | | 3.12 (.123) | 76.3 (3.003) | | 3.0 (.12) | | | | | 0 | - | 86 300 (19 400) | 362 (.141) | | 10 ⁵ | 121 000 (27 100) | 507 (.187) | |
| L1-7-1 | | 3.12 (.123) | 75.8 (2.985) | | 3.0 (.12) | | | PRELOAD | | 95 800 (21 550) | 405 (.159) | 86 300 (19 400) | 364 (.141) | | 1.5 x 10 ⁶ | 136 100 (30 600) | 574 (.218) | |
| L1-7-2 | | 3.20 (.126) | 75.9 (2.990) | | 3.0 (.12) | | | CYCUL | | 95 800 (21 550) | 394 (.155) | 86 300 (19 400) | 355 (.138) | | 10 ⁵ | 129 000 (29 000) | 531 (.201) | |
| L1-7-3 | | 3.15 (.124) | 75.9 (2.987) | | 3.0 (.12) | | | | | 95 800 (21 550) | 401 (.157) | 86 300 (19 400) | 361 (.141) | | 10 ⁵ | 112 100 (25 200) | 469 (.180) | |

D LAMINATE L1 [0/45/0/90]s/2
 D GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|--------------------------------|-----------------------|-----------------|-----------------------|----------------------|-------------------------------|-------------------|-----------------------------|--------------------|--------------------------------------|--------------------------|---|-----|-----------------------|---------------------|---------------|--------------------------------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MN/m ² (KSI) |
| L1-3-3 | L1 | 3.07 (.121) | 75.2 (2.962) | 5/8 CSK HOLE | 22.9 (.90) | 16.2 (.64) | - | STATIC PRELOAD | RT | 0 | - | NONE | - | - | - | 36,000 (12,000) | 242 (35.1) | FAILURE DUE TO PRELOAD |
| L1-3-4 | | 3.07 (.121) | 75.3 (2.966) | | 22.9 (.90) | 15.7 (.62) | - | STATIC | | 44,900 (11,200) | 215 (31.2) | NONE | - | - | - | - | - | |
| L1-8-11 | | 3.07 (.121) | 76.3 (3.003) | | 22.9 (.90) | 15.7 (.62) | - | CYCLIC | | 0 | - | 44,900 (10,100) | 192 (27.8) | .05 | 10 ³ | 52,900 (11,900) | 225 (32.7) | |
| L1-8-12 | | 3.05 (.120) | 76.2 (3.001) | | 22.9 (.90) | 15.7 (.62) | - | CYCLIC | | 0 | - | 40,500 (9,100) | 174 (25.3) | | 10 ³ | 61,400 (13,800) | 264 (38.3) | |
| L1-8-13 | | 3.05 (.120) | 73.5 (2.894) | | 22.9 (.90) | 16.0 (.63) | - | PRELOAD STATIC | | 44,900 (10,100) | 201 (29.1) | 44,900 (10,100) | 201 (29.1) | | 10 ³ | 57,400 (12,900) | 256 (37.1) | |
| L1-8-14 | | 3.10 (.122) | 74.5 (3.011) | | 22.9 (.90) | 15.7 (.62) | - | - | | 44,900 (10,100) | 190 (27.5) | 40,500 (9,100) | 171 (24.8) | | 1.5 x 10 ⁶ | 64,400 (15,000) | 293 (42.5) | |
| L1-3-1 | | 3.10 (.122) | 76.1 (3.007) | 3/8 CSK HOLE | 16.8 (.66) | 9.6 (.38) | - | STATIC | | 0 | - | NONE | - | - | - | 60,500 (13,600) | 256 (37.2) | |
| L1-3-2 | | 3.22 (.127) | 75.9 (2.984) | | 16.8 (.66) | 9.4 (.37) | - | PRELOAD STATIC | | 54,300 (12,300) | 221 (32.1) | NONE | - | - | - | 66,300 (14,900) | 271 (39.3) | |
| L1-2-13 | | 3.22 (.127) | 75.6 (2.976) | 1/8 CSK HOLE | 10.9 (.43) | 3.0 (.12) | - | STATIC | | 0 | - | NONE | - | - | - | 76,700 (17,200) | 314 (45.6) | |
| L1-2-14 | | 3.20 (.126) | 76.1 (3.001) | | 10.7 (.42) | 3.0 (.12) | - | PRELOAD STATIC | | 68,900 (15,500) | 283 (41.0) | NONE | - | - | - | 79,200 (17,800) | 325 (47.1) | |
| L1-8-7 | | 2.95 (.116) | 76.7 (3.021) | | 9.6 (.38) | 3.0 (.12) | - | CYCLIC | | 0 | - | 61,800 (13,900) | 274 (39.7) | .05 | 10 ³ | 64,800 (14,500) | 309 (44.6) | |
| L1-8-8 | | 3.18 (.125) | 76.8 (3.024) | | 10.4 (.41) | 3.0 (.12) | - | CYCLIC | | 0 | - | 61,800 (13,900) | 254 (36.8) | | 1.5 x 10 ⁶ | 80,300 (20,300) | 370 (53.7) | |
| L1-8-9 | | 3.15 (.124) | 75.7 (2.982) | | 10.2 (.40) | 3.0 (.12) | - | PRELOAD CYCLIC | | 48,900 (10,900) | 289 (41.9) | 57,400 (12,900) | 291 (42.4) | | 10 ³ | 70,200 (15,600) | 332 (48.1) | |
| L1-8-10 | | 3.18 (.125) | 75.5 (2.972) | | 10.4 (.41) | 3.0 (.12) | - | CYCLIC | | 48,900 (10,900) | 288 (41.7) | 57,400 (12,900) | 258 (37.4) | | 1.5 x 10 ⁶ | 89,000 (20,000) | 371 (53.8) | |
| L1-2-7 | | 3.02 (.119) | 76.0 (3.004) | 3/8 HP PLT | 9.4 (.37) | 0 | 1.5 (.06) | STATIC | | 0 | - | NONE | - | - | - | 96,300 (21,700) | 420 (60.9) | |
| L1-2-8 | | 3.28 (.129) | 75.9 (3.008) | | 9.4 (.37) | 0 | - | PRELOAD STATIC | | 87,000 (19,500) | 350 (50.7) | NONE | - | - | - | 119,000 (25,400) | 454 (65.9) | |

L1 LAMINATE LI [0/±45/0/90]s2
GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|--------------------------------|-----------------------|--------------|-----------------------|----------------------|-------------------------------|-------------------|-----------------------------|---------------------|--------------------------------------|--------------------------|---|-----|-----------------------|---------------------|---------------|---|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MM/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MM/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MM/m ² (KSI) |
| L1-1-2 | L1 | 3.12 (.123) | 75.6 (2.977) | NONE | 0 | 0 | 0 | STATIC PRELOAD | RT | 0 | — | NONE | — | — | — | 115 000 (32 600) | 614 (89.0) | FAILURE DURING PRELOAD FATIGUE FAILURE |
| L1-1-1 | | 3.10 (.122) | 76.8 (3.023) | | 0 | 0 | 0 | STATIC PRELOAD | | 120 000 (27 000) | 505 (72.2) | NONE | — | — | — | — | — | |
| L1-3-10 | | 3.15 (.124) | 75.6 (2.976) | | 0 | 0 | 0 | STATIC PRELOAD | | 102 700 (23 100) | 431 (61.5) | NONE | — | — | — | 160 100 (36 000) | 672 (97.5) | |
| L1-3-5 | | 3.20 (.126) | 76.1 (2.997) | | 0 | 0 | 0 | CYCLIC | | 0 | — | 97 400 (21 900) | 400 (58.0) | .05 | 1.5 x 10 ⁶ | 126 800 (28 500) | 520 (75.5) | |
| L1-3-6 | | 3.25 (.128) | 75.4 (2.967) | | 0 | 0 | 0 | PRELOAD | | 0 | — | 97 400 (21 900) | 398 (57.7) | — | 10 ⁵ | 151 800 (33 500) | 643 (93.2) | |
| L1-3-7 | | 3.23 (.127) | 76.0 (2.993) | | 0 | 0 | 0 | PRELOAD | | 0 | — | 97 400 (21 900) | 397 (57.6) | — | 10 ⁵ | 164 900 (36 700) | 642 (93.1) | |
| L1-3-8 | | 3.10 (.122) | 75.7 (2.994) | | 0 | 0 | 0 | CYCLIC | | 106 100 (24 300) | 462 (66.9) | 97 400 (21 900) | 416 (60.3) | — | 51 000 | — | — | |
| L1-3-9 | | 3.07 (.121) | 75.7 (2.980) | | 0 | 0 | 0 | CYCLIC | | 106 100 (24 300) | 465 (67.4) | 97 400 (21 900) | 419 (60.7) | — | 10 ⁵ | 144 900 (33 700) | 645 (93.5) | |

LAMINATE L1
GROSS SECTION STRESS [(0/445/0/90)]₂

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | | RESIDUAL STATIC | | REMARKS |
|-----------|-------|--------------------------------|-----------------------|----------------|-----------------------|----------------------|-------------------------------|-------------------|-----------------------------|---------------------|--------------------------------------|--------------------------|---|------|----------|---------------------|--------------------------------------|--------------------------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | STRESS MN/m ² (KSI) | |
| LI-10-1 | LI | 2.87 (.113) | 75.7 (2.980) | NONE | 0 | 0 | 0 | STATIC | RT | 0 | — | NONE | — | — | — | 26 300 (28 400) | 58.1 (84.3) | |
| LI-10-2 | | 2.94 (.116) | 75.6 (2.974) | | | | | CYCLIC | | 0 | — | 97 400 (21 900) | 43.8 (63.6) | -0.5 | 1000 | 161 000 (36 200) | 72.3 (104.9) | |
| LI-10-3 | | 2.84 (.112) | 75.5 (2.973) | | | | | | | 0 | — | 97 400 (21 900) | 43.4 (63.2) | -0.5 | 337 700 | 131 900 (31 000) | 64.2 (93.1) | |
| LI-10-4 | | 2.87 (.113) | 75.5 (2.973) | | | | | | | 0 | — | 73 400 (16 500) | 33.9 (49.1) | -1.0 | 13 800 | — | — | FATIGUE FAILURE |
| LI-10-5 | | 2.94 (.116) | 75.6 (2.974) | | | | | | | 0 | — | 73 400 (16 500) | 33.9 (49.1) | -1.0 | 700 | — | — | FATIGUE FAILURE |
| LI-10-6 | | 2.87 (.112) | 75.6 (2.976) | | | | | PRELOAD CYCLIC | | 108 100 (24 300) | 44.8 (65.0) | 73 400 (16 500) | 33.9 (49.1) | -1.0 | 15 600 | — | — | FATIGUE FAILURE |
| LI-10-7 | | 3.02 (.119) | 76.0 (2.994) | 1/8 FP HOLE | 3.0 (.12) | | | CYCLIC | | 0 | — | 48 500 (10 800) | 29.8 (43.2) | -1.0 | 83 900 | 114 800 (25 800) | 49.9 (72.4) | |
| LI-10-8 | | 2.79 (.110) | 76.0 (2.992) | | 3.0 (.12) | | | | | 0 | — | 47 200 (10 600) | 22.2 (32.2) | -1.0 | 566 600 | 108 100 (24 300) | 50.9 (73.8) | |
| LI-10-9 | | 2.97 (.117) | 75.7 (2.980) | 5/8 FP HOLE | 15.7 (.62) | | | CYCLIC | | 0 | — | 46 200 (10 400) | 20.8 (30.1) | -0.5 | 1 000 | 64 100 (14 400) | 28.5 (41.3) | STATIC COMPRESSIVE OVERLOAD |
| LI-10-10 | | 2.87 (.113) | 75.5 (2.972) | | 15.7 (.62) | | | | | 0 | — | 46 200 (10 400) | 21.5 (31.2) | -0.5 | 522 850 | 80 100 (18 000) | 31.0 (53.6) | |
| LI-10-11 | | 2.94 (.116) | 76.0 (2.993) | | 15.7 (.62) | | | | | 0 | — | 46 200 (10 400) | 20.8 (30.2) | -1.0 | 7300 | — | — | FATIGUE FAILURE |
| LI-10-12 | | 2.89 (.114) | 75.7 (2.982) | | 15.7 (.62) | | | | | 0 | — | 32 000 (7 200) | 21.5 (31.2) | -1.0 | 1842 500 | 72 100 (16 200) | 32.9 (47.7) | |
| LI-10-13 | | 3.00 (.118) | 75.4 (2.968) | | 15.7 (.62) | | | PRELOAD CYCLIC | | 52 500 (11 800) | 23.2 (33.7) | 46 200 (10 400) | 20.8 (29.9) | -0.5 | 1 000 | 63 100 (14 300) | 28.1 (40.8) | |
| LI-10-14 | | 3.00 (.118) | 76.0 (2.993) | | 15.7 (.62) | | | PRELOAD CYCLIC | | 52 500 (11 800) | 23.0 (33.4) | 46 200 (10 400) | 20.8 (29.7) | -1.0 | 22 800 | — | — | FATIGUE FAILURE |

LI C(0/24S/0/40)₂ T300/934 TAPE

| SPEC. NO. | LAYUP | THICK-NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | | RESIDUAL STATIC | | REMARKS |
|-----------|-------|----------------------------|-----------------------|----------------|-----------------------|----------------------|----------------------------|-------------------|--------------------------|--------------------|--------------------------------------|------------------------|--|------|---------|---------------------|--------------------------------------|-----------------------------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lbf) | STRESS MN/m ² (KSI) | MAX LOAD N (lbf) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lbf) | STRESS MN/m ² (KSI) | |
| L1-10-15 | L1 D | 2.97 (.117) | 76.0 (2.992) | 5/8 HP HOLE | 15.7 (.62) | | | CYCLIC | RT | 0 | - | 72,900 (16,400) | 223 (41.8) | -0.5 | 1000 | 97,400 (21,900) | 432 (72.6) | FATIGUE FAILURE |
| L1-10-16 | | 2.84 (.112) | 75.7 (2.991) | | 15.7 (.62) | | | | | 0 | - | 72,900 (16,400) | 239 (49.1) | -0.5 | 1793 | - | - | FATIGUE FAILURE |
| L1-10-17 | | 3.00 (.118) | 76.0 (2.992) | | 15.7 (.62) | | | | | 0 | - | 72,900 (16,400) | 321 (61.5) | -1.0 | 3100 | - | - | FATIGUE FAILURE |
| L1-10-18 | | 3.00 (.118) | 76.0 (2.992) | | 15.7 (.62) | | | | | 0 | - | 49,400 (11,100) | 214 (31.4) | -1.0 | 150000 | 105,900 (23,800) | 465 (77.4) | |
| L1-10-19 | | 3.02 (.119) | 76.0 (2.992) | 1/8 EP SURF | 3.0 (.12) | | | CYCLIC | | 0 | - | 71,200 (16,000) | 310 (41.9) | -1.0 | 36100 | - | - | FATIGUE FAILURE |
| L1-10-20 | | 3.02 (.119) | 75.6 (2.975) | | 3.0 (.12) | | | | | 0 | - | 48,900 (11,000) | 214 (31.1) | -1.0 | 741 000 | 101,000 (22,700) | 442 (64.1) | |
| L1-10-21 | | 2.92 (.115) | 76.1 (2.996) | 5/8 EP SURF | 15.7 (.62) | | | CYCLIC | | 0 | - | 47,100 (10,580) | 212 (30.7) | -0.5 | 1 | - | - | STATIC FAILURE AT (10,580 lbf) |
| L1-10-22 | | 2.97 (.117) | 76.1 (2.996) | | 15.7 (.62) | | | | | 0 | - | 47,600 (10,700) | 210 (30.5) | -0.5 | 150000 | 76,500 (17,200) | 338 (49.1) | |
| L1-10-23 | | 2.81 (.113) | 75.6 (2.976) | | 15.7 (.62) | | | | | 0 | - | 46,100 (10,360) | 212 (30.8) | -1.0 | 1 | - | - | STATIC FAILURE AT (10,360 lbf) |
| L1-10-24 | | 2.81 (.113) | 75.6 (2.976) | | 15.7 (.62) | | | | | 0 | - | 32,900 (7,400) | 152 (22.0) | -1.0 | 150000 | 62,300 (14,000) | 287 (41.4) | |
| L1-10-25 | | 3.02 (.119) | 76.1 (2.996) | | 15.7 (.62) | | | PRELOAD CYCLIC | | 51,400 (11,560) | 223 (32.4) | - | - | - | - | - | - | FAILURE DUE TO PRELOAD |
| L1-10-26 | | 3.02 (.119) | 76.0 (2.992) | 1/8 HP SURF | 3.0 (.12) | 0 | | CYCLIC | | 0 | - | 73,100 (16,500) | 319 (46.3) | -1.0 | 23800 | 132,100 (29,700) | 575 (83.4) | |
| L1-10-27 | | 2.94 (.116) | 75.7 (2.981) | | 3.0 (.12) | 0 | | | | 0 | - | 58,300 (13,100) | 241 (37.3) | -1.0 | 114 600 | 129,000 (29,000) | 578 (83.4) | |

2 LAMINATE L1 [(0/±45/0/40)₂] T300/434 TAPE

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | | RESIDUAL STATIC | | REMARKS |
|-----------|-------|--------------------------------|-----------------------|------------------|-----------------------|----------------------|-------------------------------|-------------------|-----------------------------|-------------------|--------------------------------------|--------------------------|---|------|--------|--------------------|--------------------------------------|-----------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | STRESS MN/m ² (KSI) | |
| L1-10-28 | L1 | 294 (11.6) | 75.5 (2.972) | 5/8 NP SLT | 16.8 (.66) | 0 | 0 | CYCLIC | RT | 0 | - | 80100 (18000) | 360 (52.2) | -0.5 | 1000 | 108100 (24300) | 486 (70.5) | FATIGUE FAILURE |
| L1-10-29 | | 297 (11.7) | 76.0 (2.993) | | 16.8 (.66) | 0 | 0 | | | 0 | - | 80100 (18000) | 354 (51.4) | -0.5 | 272400 | - | - | FATIGUE FAILURE |
| L1-10-30 | | 292 (11.5) | 76.0 (2.992) | | 16.8 (.66) | 0 | 0 | | | 0 | - | 73400 (16500) | 331 (48.0) | -1.0 | 400 | - | - | FATIGUE FAILURE |
| L1-10-31 | | 292 (11.5) | 76.0 (2.994) | | 16.8 (.66) | 0 | 0 | | | 0 | - | 54300 (12200) | 244 (35.4) | -1.0 | 742400 | - | - | FATIGUE FAILURE |
| L1-10-32 | | 297 (11.7) | 76.0 (2.994) | 5/8 CSIC HOLE | 22.3 (.88) | 15.7 (.62) | 0 | CYCLIC | | 0 | - | 45300 (10000) | 197 (27.1) | -1.0 | 50800 | - | - | FATIGUE FAILURE |
| L1-10-33 | | 289 (11.4) | 76.0 (2.992) | | 22.3 (.88) | 15.7 (.62) | 0 | PRELOAD CYCLIC | | 0 | - | 29900 (6500) | 132 (19.1) | -1.0 | 150000 | 66700 (15000) | 303 (44.0) | FATIGUE FAILURE |
| L1-10-34 | | 300 (11.8) | 75.6 (2.975) | | 22.6 (.89) | 15.7 (.62) | 52500 (11800) | | | 52500 (11800) | 232 (33.6) | 42300 (9500) | 197 (27.1) | -1.0 | 16600 | - | - | FATIGUE FAILURE |
| L1-11-1 | | 287 (11.3) | 75.5 (2.973) | 5/8 D-CORROD | | | 0 | CYCLIC | | 0 | - | 91400 (21900) | 450 (65.2) | -0.5 | 1000 | 169000 (38000) | 780 (113.1) | FATIGUE FAILURE |
| L1-11-2 | | 289 (11.4) | 75.7 (2.982) | | | | 0 | | | 0 | - | 91400 (21900) | 444 (64.4) | -0.5 | 15780 | 124500 (28000) | 568 (81.4) | FATIGUE FAILURE |
| L1-11-3 | | 294 (11.6) | 75.5 (2.973) | | | | 0 | | | 0 | - | 91400 (21900) | 438 (63.5) | -1.0 | 77 | - | - | FATIGUE FAILURE |
| L1-11-4 | | 294 (11.6) | 75.3 (2.965) | | | | 0 | | | 0 | - | 73400 (16500) | 331 (48.0) | -1.0 | 12560 | - | - | FATIGUE FAILURE |
| L1-11-5 | | 287 (11.3) | 75.3 (2.975) | | | | 0 | | | 0 | - | 91400 (21900) | 449 (65.1) | +0.1 | 1000 | 130300 (33800) | 693 (100.5) | FATIGUE FAILURE |
| L1-11-6 | | 282 (11.1) | 75.3 (2.975) | | | | 0 | | | 0 | - | 91400 (21900) | 457 (66.3) | +0.1 | 150000 | 117900 (26500) | 553 (80.3) | FATIGUE FAILURE |
| L1-11-7 | | 292 (11.5) | 75.5 (2.972) | | | | 108100 (24300) | PRELOAD CYCLIC | | 108100 (24300) | 490 (71.1) | 73400 (16500) | 331 (48.0) | -1.0 | 1000 | 154300 (34700) | 700 (101.5) | FATIGUE FAILURE |

LAMINATE L1 [0/±45/0/90]_s] T300 / 434 TAP

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | | RESIDUAL STATIC | | REMARKS |
|-----------|-------|--------------------------------|-----------------------|----------------|-----------------------|----------------------|----------------------------|-------------------|--------------------------|---------------------|--------------------------------------|--------------------------|---|-----|---------------------|---------------------|--------------------------------------|-----------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | STRESS MN/m ² (KSI) | |
| L2-1-7 | L2 | 3.10 (.122) | 76.4 (3.007) | S/B FP NONE | 15.7 (.62) | | - | STATIC | RT | 0 | - | NONE | - | - | - | 99,000 (22,230) | 418 (60.6) | |
| L2-1-8 | | 3.18 (.125) | 76.2 (3.000) | | 15.7 (.62) | | - | PRELOAD STATIC | | 89,200 (20,000) | 368 (53.3) | NONE | - | - | - | 117,600 (26,150) | 484 (70.5) | |
| L2-1-30 | | 3.18 (.125) | 76.1 (2.996) | | 15.7 (.62) | | - | CYCLIC | | 0 | - | 80,000 (18,000) | 332 (48.1) | .05 | 10 ³ | 116,500 (26,200) | 482 (70.0) | |
| L2-1-29 | | 3.12 (.123) | 75.4 (2.994) | | 15.7 (.62) | | - | | | 0 | - | 80,100 (18,000) | 340 (49.3) | | 1.5x10 ⁶ | 132,800 (30,400) | 574 (83.2) | |
| L2-1-32 | | 3.18 (.123) | 75.9 (2.991) | | 15.7 (.62) | | - | PRELOAD CYCLIC | | 89,000 (20,000) | 370 (53.6) | 80,000 (18,000) | 332 (48.2) | | 10 ³ | 118,800 (26,700) | 483 (71.5) | |
| L2-1-31 | | 3.12 (.123) | 75.9 (2.991) | | 15.7 (.62) | | - | | | 89,000 (20,000) | 375 (54.4) | 80,000 (18,000) | 338 (49.0) | | 1.5x10 ⁶ | 121,900 (27,400) | 514 (74.6) | |
| L2-1-5 | | 3.18 (.125) | 74.4 (2.930) | S/B FP NONE | 9.6 (.38) | | - | STATIC | | 0 | - | NONE | - | - | - | 127,700 (28,700) | 540 (78.4) | |
| L2-1-6 | | 3.18 (.125) | 74.4 (2.930) | | 9.6 (.38) | | - | PRELOAD STATIC | | 115,000 (25,800) | 485 (70.4) | NONE | - | - | - | 139,200 (31,300) | 588 (85.3) | |
| L2-1-3 | | 3.12 (.123) | 74.6 (2.934) | 1/B FP NONE | 3.0 (.12) | | - | STATIC | | 0 | - | NONE | - | - | - | 136,600 (30,700) | 584 (85.0) | |
| L2-1-4 | | 3.25 (.128) | 74.4 (2.931) | | 3.0 (.12) | | - | PRELOAD STATIC | | 122,800 (27,600) | 507 (73.6) | NONE | - | - | - | 134,100 (30,600) | 563 (81.6) | |
| L2-1-26 | | 3.12 (.123) | 74.4 (2.930) | | 3.0 (.12) | | - | CYCLIC | | 0 | - | 110,300 (24,800) | 462 (67.0) | .05 | 10 ³ | 161,500 (36,300) | 607 (88.1) | |
| L2-1-25 | | 3.10 (.122) | 75.3 (2.993) | | 3.0 (.12) | | - | | | 0 | - | 110,300 (24,800) | 473 (68.6) | | 1.5x10 ⁶ | 175,300 (39,400) | 751 (108.9) | |
| L2-1-28 | | 3.18 (.125) | 75.9 (2.991) | | 3.0 (.12) | | - | PRELOAD CYCLIC | | 122,800 (27,600) | 509 (73.8) | 110,300 (24,800) | 457 (66.3) | | 10 ³ | 145,000 (32,600) | 601 (87.2) | |
| L2-1-27 | | 3.05 (.120) | 76.2 (3.001) | | 3.0 (.12) | | - | | | 122,800 (27,600) | 528 (76.6) | 110,300 (24,800) | 475 (68.9) | | 1.5x10 ⁶ | 145,000 (32,600) | 601 (87.2) | FATIGUE FAILURE |

LAMINATE L2
GROSS SECTION STRESS [(0.3 / ±0.2) / 5]

| SPEC. NO. | LAYUP | THICK-NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|----------------------------|-----------------------|---------------|-----------------------|----------------------|----------------------------|-------------------|--------------------------|---------------------|--------------------------------------|-----------------------|--|-----|---------------------|---------------------|----------------|--|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MM/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MM/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MM/m ² (KSI) |
| L2-1-17 | L2 | 3.20 (.126) | 74.4 (2.931) | 5/8 FP SMT | 15.2 (.60) | | - | STATIC | RT | 0 | - | NONE | - | - | - | 109,000 (24,500) | 457 (66.3) | |
| L2-1-18 | | 3.15 (.124) | 73.8 (2.905) | | 15.7 (.62) | | - | PRELOAD STATIC | | 98,100 (22,000) | 422 (61.2) | NONE | - | - | - | 100,500 (22,600) | 432 (62.7) | |
| L2-1-41 | | 3.22 (.127) | 74.3 (2.924) | | 16.0 (.63) | | - | CYCIL | | 0 | - | 88,100 (19,800) | 358 (51.4) | .05 | 1.5x10 ⁶ | 137,000 (30,800) | 556 (80.1) | |
| L2-1-42 | | 3.20 (.126) | 75.9 (2.987) | | 16.0 (.63) | | - | PRELOAD CYCIL | | 0 | - | 88,100 (19,800) | 363 (52.6) | | 10 ³ | 119,200 (26,800) | 491 (71.2) | |
| L2-1-43 | | 3.25 (.128) | 76.0 (2.993) | | 16.0 (.63) | | - | PRELOAD CYCIL | | 98,100 (22,000) | 393 (57.6) | 88,100 (19,800) | 356 (51.7) | | 1.5x10 ⁶ | 130,800 (29,400) | 529 (76.7) | |
| L2-1-44 | | 3.15 (.124) | 76.4 (3.008) | | 15.7 (.62) | | - | | | 98,100 (22,000) | 407 (59.1) | 88,100 (19,800) | 366 (53.1) | | 10 ³ | 113,900 (25,000) | 473 (68.6) | |
| L2-1-13 | | 3.12 (.123) | 73.6 (2.898) | 2/8 FP SMT | 9.4 (.37) | | - | STATIC | | 0 | - | NONE | - | - | - | 133,000 (29,900) | 578 (83.9) | |
| L2-1-14 | | 3.18 (.125) | 75.1 (2.959) | | 9.4 (.37) | | - | PRELOAD STATIC | | 119,600 (26,900) | 301 (72.7) | NONE | - | - | - | 129,200 (28,050) | 541 (78.3) | |
| L2-1-9 | | 3.18 (.125) | 74.4 (2.929) | 1/8 FP SMT | 3.0 (.12) | | - | STATIC | | 0 | - | NONE | - | - | - | 138,800 (31,200) | 587 (85.2) | |
| L2-1-10 | | 3.23 (.127) | 74.5 (2.932) | | 3.3 (.13) | | - | PRELOAD STATIC | | 125,000 (28,100) | 370 (75.5) | NONE | - | - | - | 140,100 (31,500) | 583 (84.6) | |
| L2-1-33 | | 3.18 (.125) | 75.9 (2.987) | | 3.3 (.13) | | - | CYCIL | | 0 | - | 112,500 (25,300) | 467 (67.8) | .05 | 321,600 | - | - | FAILURE DURING CYCLIC TEST DUE TO OVERLOAD |
| L2-1-34 | | 3.22 (.127) | 76.3 (3.003) | | 3.0 (.12) | | - | PRELOAD CYCIL | | 0 | - | 112,500 (25,300) | 457 (66.3) | | 1,004 | 142,800 (32,000) | 627 (90.0) | |
| L2-1-35 | | 3.12 (.123) | 76.1 (2.998) | | 3.3 (.13) | | - | PRELOAD CYCIL | | 125,000 (28,100) | 325 (76.2) | 112,500 (25,300) | 473 (68.6) | | 1,500,150 | 176,100 (39,600) | 700 (101.4) | |
| L2-1-36 | | 3.20 (.126) | 75.7 (2.990) | | 2.3 (.13) | | - | | | 125,000 (28,100) | 516 (74.3) | 112,500 (25,300) | 465 (67.4) | | 1,003 | 150,300 (33,800) | 620 (90.0) | |



LAMINATE L2
 GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | | RESIDUAL STATIC | | REMARKS |
|-----------|-------|--------------------------------|-----------------------|---------------|-----------------------|----------------------|----------------------------|-----------------------------|--------------------------|---------------------|--------------------------------------|--------------------------|---|------|-----------------|---------------------|--------------------------------------|-------------------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | STRESS MN/m ² (KSI) | |
| L2-1-19 | → | 3.18 (.125) | 75.1 (2.955) | 5/8 WF SMT | 15.2 (.60) | 0 | 1.5 (.06) | Static PRELOAD Static | RT | 0 | None | None | None | - | - | 176,100 (39,400) | 739 (101.2) | Failure due to overload |
| L2-1-20 | → | 3.07 (.121) | 75.1 (2.955) | 5/8 WF SMT | 15.2 (.60) | 0 | 1.5 (.06) | Static | RT | 136,600 (30,500) | 678 (96.3) | None | None | - | - | - | - | Failure due to overload |
| L2-1-45 | → | 3.20 (.125) | 76.5 (3.011) | 5/8 WF SMT | 15.5 (.61) | 0 | 1.5 (.06) | Cyclic | RT | 0 | None | 124,800 (28,000) | 517 (73.0) | -0.5 | 267,270 | - | - | Failure due to overload |
| L2-1-46 | → | 3.15 (.124) | 74.2 (2.925) | 5/8 WF SMT | 14.9 (.59) | 0 | 1.5 (.06) | Static PRELOAD Cyclic | RT | 0 | None | 124,800 (28,000) | 517 (73.0) | -0.5 | 10 ³ | 165,000 (37,200) | 688 (99.8) | Failure due to overload |
| L2-1-47 | → | 3.18 (.125) | 74.6 (2.937) | 5/8 WF SMT | 14.7 (.58) | 0 | 1.5 (.06) | Static PRELOAD Cyclic | RT | 41,000 (9,100) | 58.0 (8.4) | 124,800 (28,000) | 517 (73.0) | -0.5 | 105,245 | - | - | Failure due to overload |
| L2-1-48 | → | 3.02 (.119) | 76.5 (3.011) | 5/8 WF SMT | 15.1 (.60) | 0 | 1.5 (.06) | Cyclic | RT | 41,000 (9,100) | 58.0 (8.4) | 124,800 (28,000) | 517 (73.0) | -0.5 | 46 | - | - | Failure due to overload |
| L2-1-15 | → | 3.25 (.128) | 75.0 (2.952) | 5/8 WF SMT | 9.4 (.37) | 0 | 1.5 (.06) | Static PRELOAD Static | RT | 0 | None | None | None | - | - | 147,700 (32,800) | 737 (104.9) | |
| L2-1-16 | → | 3.12 (.123) | 73.4 (2.890) | 5/8 WF SMT | 10.2 (.40) | 0 | 1.5 (.06) | Static PRELOAD Static | RT | 141,100 (31,400) | 76.6 (10.9) | None | None | - | - | 165,000 (37,200) | 720 (101.4) | |
| L2-1-11 | → | 3.15 (.124) | 74.9 (2.950) | 5/8 WF SMT | 3.0 (.12) | 0 | 1.5 (.06) | Static PRELOAD Static | RT | 0 | None | None | None | - | - | 149,900 (33,200) | 635 (90.1) | |
| L2-1-12 | → | 3.22 (.127) | 75.1 (2.957) | 5/8 WF SMT | 3.3 (.13) | 0 | 1.5 (.06) | Static PRELOAD Static | RT | 136,600 (30,500) | 557 (80.8) | None | None | - | - | 178,800 (40,200) | 738 (107.0) | |
| L2-1-27 | → | 3.07 (.121) | 74.4 (2.907) | 5/8 WF SMT | 3.0 (.12) | 0 | 1.5 (.06) | Cyclic | RT | 0 | None | 124,800 (28,000) | 517 (73.0) | -0.5 | 1,500 | 165 (44,800) | 845 (123.1) | |
| L2-1-38 | → | 3.10 (.123) | 74.2 (2.937) | 5/8 WF SMT | 3.0 (.12) | 0 | 1.5 (.06) | Cyclic | RT | 0 | None | 124,800 (28,000) | 517 (73.0) | -0.5 | 1,004 | 147,900 (33,200) | 838 (121.8) | |
| L2-1-39 | → | 3.22 (.127) | 74.5 (2.937) | 5/8 WF SMT | 3.0 (.12) | 0 | 1.5 (.06) | Static PRELOAD Cyclic | RT | 136,600 (30,500) | 547 (78.1) | 124,800 (28,000) | 517 (73.0) | -0.5 | 1,500 | 209,500 (47,100) | 849 (123.1) | |
| L2-1-40 | → | 3.10 (.123) | 74.3 (2.937) | 5/8 WF SMT | 3.0 (.12) | 0 | 1.5 (.06) | Static PRELOAD Cyclic | RT | 136,600 (30,500) | 571 (81.8) | 124,800 (28,000) | 517 (73.0) | -0.5 | 1,421 | 192,100 (43,200) | 812 (117.8) | |

→ LAMINATE L2 [0₃/±80]₂ S
→ GROSS SECTION

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|--------------------------------|-----------------------|--------------|-----------------------|----------------------|-------------------------------|-----------------------------|-----------------------------|-------------------|--------------------------------------|--------------------------|---|-----|--------------------|-------------------|----------------|---|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MN/m ² (KSI) |
| L2-1-1 | L2 | 3.18 (.125) | 74.5 (2.932) | NONE | 0 | 0 | 0 | STATIC PRELOAD STATIC | RT | 0 | - | NONE | - | - | - | 203100 (44000) | 827 (120.0) | ENTIRE FAILURE |
| L2-1-2 | | 3.17 (.125) | 74.5 (2.932) | | 0 | 0 | 0 | | | 170400 (39650) | 74.6 (108.2) | NONE | - | - | - | 183500 (40800) | 618 (118.6) | |
| L2-1-21 | | 3.17 (.125) | 74.2 (2.931) | | | | | CYCUL | | 0 | - | 158800 (35100) | 65.6 (95.2) | .05 | 10280 | - | - | |
| L2-1-22 | | 3.15 (.124) | 74.1 (2.930) | | | | | | | 0 | - | 158800 (35100) | 66.1 (95.8) | | 1003 | 203100 (44000) | 849 (123.2) | |
| L2-1-23 | | 3.17 (.125) | 75.7 (2.981) | | | | | PRELOAD CYCUL | | 170400 (39650) | 73.4 (106.4) | 158800 (35100) | 66.1 (95.8) | | 4594 | - | - | |
| L2-1-24 | | 3.10 (.122) | 74.1 (2.935) | | | | | | | 170400 (39650) | 74.8 (108.5) | - | - | - | - | - | - | STATIC OVERLOAD FAILURE DURING CYCLIC TEST |

LAMINATE L2 [(0₂/±80)₂]s
GROSS SECTION

 LAMINATE L2 $[0_3/\pm 80]_2$ S
 GROSS SECTION

| SPEC. NO. | LAYUP | THICK-NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|----------------------------|-----------------------|-----------------|-----------------------|----------------------|----------------------------|-------------------|--------------------------|-------------------|--------------------------------------|--------------------------|---|------|---------------------|-------------------|---------------|---|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MM/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MM/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MM/m ² (KSI) |
| L2-2-1 | L2 | 3.00 (.118) | 75.2 (2.960) | 5/8 FP HOLE | 15.7 (.62) | | | STATIC | RT | 0 | - | NONE | - | - | - | 99200 (22300) | 440 (63.8) | LOW AUTOCLAVE PRESSURE = 345 kN/m ² (50 psi) |
| L2-2-2 | | 3.18 (.125) | 75.1 (2.958) | | 15.7 (.62) | | | PRELOAD STATIC | | 89400 (20100) | 375 (54.4) | NONE | - | - | - | 104100 (23400) | 436 (63.3) | |
| L2-2-3 | | 3.18 (.125) | 75.2 (2.961) | | 15.7 (.62) | | | CYCLOC | | 0 | - | 80500 (18100) | 337 (48.9) | 0.05 | 1.5x10 ⁶ | 131700 (29600) | 552 (80.0) | |
| L2-2-4 | | 3.15 (.124) | 75.2 (2.961) | | 15.7 (.62) | | | | | 0 | - | 80500 (18100) | 340 (49.3) | | 10 ³ | 102100 (23100) | 434 (62.9) | |
| L2-2-5 | | 3.18 (.125) | 75.3 (2.963) | | 15.7 (.62) | | | PRELOAD CYCLOC | | 89400 (20100) | 374 (54.3) | 80500 (18100) | 337 (48.9) | | 1.5x10 ⁶ | 137000 (30800) | 514 (82.2) | |
| L2-2-6 | | 3.20 (.126) | 75.2 (2.961) | | 15.7 (.62) | | | | | 99400 (22400) | 372 (53.9) | 80500 (18100) | 334 (48.5) | | 10 ³ | 109400 (24600) | 454 (65.9) | |
| L2-3-1 | | 3.10 (.122) | 74.4 (2.948) | 5/8 FP HOLE | 15.7 (.62) | | | STATIC | | 0 | - | NONE | - | - | - | 101900 (22900) | 429 (63.7) | LOW AUTOCLAVE PRESSURE = 172 kN/m ² (25 psi) |
| L2-3-2 | | 3.12 (.123) | 74.3 (2.927) | | 15.7 (.62) | | | PRELOAD STATIC | | 91000 (20600) | 294 (57.2) | NONE | - | - | - | 102300 (23000) | 440 (63.8) | |
| L2-4-7 | | 3.28 (.129) | 75.2 (2.961) | 5/8 FP HOLE | 15.7 (.62) | | | STATIC | | 0 | - | NONE | - | - | - | 112500 (25300) | 456 (66.2) | LOW AUTOCLAVE PRESSURE = 86 kN/m ² (12.5 psi) |
| L2-4-2 | | 3.18 (.125) | 75.2 (2.962) | 5/8 CSL HOLE | 23.4 (.92) | 15.7 (.62) | | STATIC | | 0 | - | NONE | - | - | - | 89500 (20200) | 376 (54.6) | |
| L2-4-3 | | 3.12 (.123) | 75.2 (2.962) | | 23.4 (.92) | 15.7 (.62) | | CYCLOC | | 0 | - | 61900 (13900) | 261 (37.8) | 0.05 | 10 ³ | 95200 (21400) | 405 (58.7) | |
| L2-4-4 | | 3.15 (.124) | 75.3 (2.963) | | 23.4 (.92) | 15.7 (.62) | | | | 0 | - | 60000 (13500) | 253 (36.7) | | 1.5x10 ⁶ | 121000 (27200) | 510 (74.0) | |
| L2-4-5 | | 3.18 (.125) | 75.2 (2.961) | | 23.4 (.92) | 15.7 (.62) | | PRELOAD CYCLOC | | 79300 (17700) | 311 (45.1) | 60000 (13500) | 244 (35.4) | | - | 111000 (24900) | 476 (68.1) | PRELOAD FOR NCA PRELOAD |
| L2-4-6 | | 3.28 (.129) | 75.2 (2.961) | | 23.4 (.92) | 15.7 (.62) | | | | 64900 (15000) | 272 (39.4) | 60000 (13500) | 244 (35.4) | | 1.5x10 ⁶ | 111000 (24900) | 476 (68.1) | |

1) LAMINATE L2 (C/S / ±40) 2, 3

2) GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|--------------------------------|-----------------------|---------------|-----------------------|----------------------|-------------------------------|-------------------|-----------------------------|--------------------|--------------------------------------|--------------------------|---|-----|---|---------------------|----------------|--------------------------------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MN/m ² (KSI) |
| L3-1-7 | L3 | 3.30 (.130) | 75.2 (2.961) | 5/8 FP WOE | 15.7 (.62) | | - | STATIC | RT | 0 | - | NONE | - | - | - | 110 800 (24 000) | 43.6 (63.2) | FAILURE DURING PRELOAD |
| L3-1-8 | | 3.23 (.127) | 75.1 (2.957) | | 15.7 (.62) | | - | PRELOAD STATIC | | 9400 (2 300) | 34.1 (5.67) | NONE | - | - | - | - | - | |
| L3-1-35 | | 3.25 (.128) | 75.1 (2.958) | | 15.7 (.62) | | - | CYCLOC | | 0 | - | 76 900 (17 300) | 31.5 (45.7) | .05 | 10 ³ | 124 600 (28 000) | 55.9 (81.1) | |
| L3-1-36 | | 3.25 (.128) | 75.1 (2.957) | | 15.7 (.62) | | - | PRELOAD CYCLOC | | 85 400 (19 200) | 34.1 (4.93) | 76 900 (17 300) | 31.5 (45.7) | | 1.5 x 10 ⁶ (2.2 x 10 ⁶) | 103 600 (23 300) | 43.5 (61.6) | |
| L3-1-37 | | 3.33 (.131) | 75.1 (2.958) | | 15.7 (.62) | | - | | | 85 400 (19 200) | 34.1 (4.93) | 76 900 (17 300) | 30.8 (44.4) | | 1.5 x 10 ⁶ (2.2 x 10 ⁶) | 104 000 (23 300) | 43.6 (63.2) | |
| L3-1-38 | | 3.33 (.133) | 75.1 (2.957) | | 14.0 (.63) | | - | | | 85 400 (19 200) | 33.6 (48.8) | 76 900 (17 300) | 30.3 (44.0) | | 10 ³ | 104 100 (23 400) | 41.0 (59.3) | |
| L3-1-17 | L3 | 3.30 (.130) | 74.9 (2.951) | 5/8 FP SUT | 14.0 (.63) | | - | STATIC | | 0 | - | NONE | - | - | - | 98 500 (22 150) | 39.8 (57.7) | |
| L3-1-18 | | 3.38 (.133) | 75.0 (2.953) | | 15.7 (.62) | | - | PRELOAD STATIC | | 88 700 (19 950) | 35.0 (50.8) | NONE | - | - | - | 95 400 (21 450) | 37.6 (54.6) | |
| L3-1-55 | | 3.30 (.130) | 75.2 (2.959) | | 15.7 (.62) | | - | CYCLOC | | 0 | - | 80 100 (18 000) | 32.3 (46.8) | .05 | 1 394 700 | 102 700 (23 100) | 41.4 (60.0) | |
| L3-1-56 | | 3.43 (.135) | 75.1 (2.957) | | 15.7 (.62) | | - | | | 0 | - | 80 100 (18 000) | 31.1 (45.1) | | 10 ³ | 95 200 (21 100) | 37.0 (53.6) | |
| L3-1-57 | | 3.35 (.132) | 75.1 (2.956) | | 15.7 (.62) | | - | PRELOAD CYCLOC | | 89 100 (19 950) | 35.2 (51.1) | 80 100 (18 000) | 31.8 (46.1) | | 1 500 281 | 97 000 (21 900) | 38.5 (55.4) | |
| L3-1-58 | | 3.33 (.131) | 75.2 (2.960) | | 15.7 (.62) | | - | | | 89 100 (20 100) | 35.7 (51.8) | 80 100 (18 000) | 32.0 (46.4) | | 10 ³ | 105 900 (23 800) | 42.3 (61.4) | |
| L3-2-4 | L3 | 2.89 (.114) | 75.0 (2.953) | 5/8 FP SUT | 15.7 (.62) | | - | STATIC | | 0 | - | NONE | - | - | - | 108 100 (24 300) | 31.4 (45.5) | |
| L3-2-5 | | 2.97 (.117) | 75.0 (2.953) | | 15.7 (.62) | | - | PRELOAD STATIC | | 11 200 (2 500) | 27.4 (39.0) | NONE | - | - | - | 62 000 (13 900) | 27.9 (40.4) | |

UNIMATED L3 (10/430/8/30/0) 2.5 * RY OF S-GLOSS IN L3-1-X, SPEC. NO. L3-2-X ALL GRAPHING

| SPEC. NO. | LAYUP | THICKNESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | | RESIDUAL STATIC | | REMARKS |
|-----------|-------|---------------------------|-----------------------|-------------|-----------------------|----------------------|----------------------------|-----------|--------------------------|---------------------|--------------------------------------|--------------------------|---|-----|------------------------|---------------------|--------------------------------------|---|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | STRESS MN/m ² (KSI) | |
| L3-1-6 | L3 | 3.38 (.133) | 75.2 (2.962) | 3/8 FP HOLE | 9.6 (.38) | | | STATIC | RT | 0 | - | NONE | - | - | - | 113 400 (25 500) | 446 (61.7) | |
| L3-1-5 | | 2.40 (.134) | 75.3 (2.964) | | 9.6 (.38) | | | PRELOAD | | 106 500 (23 940) | 416 (60.3) | NONE | - | - | - | 119 000 (26 750) | 464 (67.3) | |
| L3-1-29 | | 2.30 (.136) | 75.1 (2.957) | | 9.4 (.37) | | | CYCLIC | | 0 | - | 91 000 (20 400) | 370 (53.6) | .05 | 1.5 x 10 ⁶ | 111 200 (25 000) | 448 (65.0) | |
| L3-1-30 | | 2.28 (.121) | 75.2 (2.959) | | 9.4 (.37) | | | | | 0 | - | 91 000 (20 400) | 372 (54.0) | | 10 ³ | 116 500 (26 200) | 473 (68.3) | |
| L3-1-32 | | 2.30 (.136) | 75.1 (2.957) | | 9.6 (.38) | | | PRELOAD | | 102 100 (22 950) | 412 (59.7) | 91 000 (20 400) | 370 (53.6) | | 7.6 x 10 ⁵ | - | - | FAILURE DURING CYCLIC FAILURE OVERLOAD |
| L3-1-34 | | 2.35 (.132) | 75.1 (2.957) | | 9.4 (.37) | | | CYCLIC | | 102 100 (22 950) | 405 (58.8) | 91 000 (20 400) | 364 (52.8) | | 10 ³ | 124 100 (27 900) | 493 (71.5) | |
| L3-1-13 | L3 | 3.38 (.133) | 75.2 (2.962) | 3/8 FP HOLE | 9.4 (.37) | | | STATIC | | 0 | - | NONE | - | - | - | 114 500 (25 750) | 451 (65.4) | |
| L3-1-14 | | 2.35 (.132) | 75.2 (2.960) | | 9.6 (.38) | | | PRELOAD | | 102 700 (22 900) | 409 (59.4) | NONE | - | - | - | 114 800 (25 800) | 455 (66.0) | |
| L3-1-47 | | 3.18 (.125) | 74.4 (2.924) | | 9.4 (.37) | | | CYCLIC | | 0 | - | 93 000 (20 900) | 394 (57.1) | .05 | 1.33 x 10 ⁶ | 115 500 (25 800) | 480 (71.0) | |
| L3-1-48 | | 3.35 (.132) | 74.6 (2.936) | | 9.1 (.36) | | | | | 0 | - | 93 000 (20 900) | 372 (53.9) | | 10 ³ | 109 400 (24 500) | 437 (63.4) | |
| L3-1-49 | | 3.28 (.127) | 75.1 (2.957) | | 9.4 (.37) | | | PRELOAD | | 103 200 (23 200) | 419 (60.8) | 93 000 (20 900) | 378 (54.8) | | 1.5 x 10 ⁶ | 110 100 (24 600) | 450 (65.3) | |
| L3-1-50 | | 3.25 (.128) | 75.1 (2.957) | | 9.1 (.36) | | | CYCLIC | | 102 100 (22 950) | 410 (59.4) | 93 000 (20 900) | 369 (53.5) | | 10 ³ | 111 600 (25 100) | 443 (64.3) | |

LAMINATE L3 [(0/130/0°/-30/0)2]s * PLY OF S-Glass IN SPEC L3-1-X
 GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|--------------------------------|-----------------------|-------------|-----------------------|----------------------|----------------------------|-------------------|--------------------------|---------------------|--------------------------------------|--------------------------|---|-----|--------------------|---------------------|---------------|--------------------------------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MN/m ² (KSI) |
| L3-1-3 | L3 | 3.35 (.132) | 75.0 (2.954) | 1/8 FP HOLE | 3.0 (.12) | | | STATIC | RT | 0 | - | NONE | - | - | - | 150 300 (33 300) | 599 (84.2) | FATIGUE FAILURE |
| L3-1-4 | | 3.20 (.126) | 75.3 (2.963) | | 3.0 (.12) | | | PRELOAD STATIC | | 135 700 (30 500) | 563 (81.7) | NONE | - | - | - | 147 200 (33 100) | 611 (88.5) | |
| L3-1-25 | | 3.32 (.131) | 75.1 (2.958) | | 3.0 (.12) | | | CYCLOC | | 0 | - | 121 200 (27 400) | 487 (69.7) | .05 | 40 | - | - | |
| L3-1-26 | | 3.32 (.131) | 75.0 (2.954) | | 3.0 (.12) | | | | | 0 | - | 121 900 (27 400) | 488 (69.8) | | 10 ³ | 145 400 (32 700) | 583 (84.5) | |
| L3-1-27 | | 3.32 (.131) | 75.1 (2.957) | | 3.0 (.12) | | | PRELOAD CYCLOC | | 135 700 (30 500) | 543 (78.7) | 121 900 (27 400) | 487 (69.7) | | 123 000 | 117 700 (26 200) | 591 (84.2) | |
| L3-1-28 | | 3.30 (.130) | 75.1 (2.956) | | 3.0 (.12) | | | | | 135 700 (30 500) | 547 (79.4) | 121 900 (27 400) | 492 (71.3) | | 10 ³ | 146 800 (32 700) | 592 (84.2) | |
| L3-1-9 | L3 | 3.40 (.134) | 75.1 (2.957) | 1/8 FP SLIT | 3.0 (.12) | | | STATIC | | 0 | - | NONE | - | - | - | 149 300 (33 300) | 580 (84.2) | |
| L3-1-10 | | 3.35 (.132) | 75.0 (2.955) | | 3.3 (.13) | | | PRELOAD STATIC | | 133 400 (30 000) | 530 (76.4) | NONE | - | - | - | 146 300 (32 900) | 581 (84.3) | |
| L3-1-39 | | 3.35 (.132) | 75.1 (2.957) | | 3.3 (.13) | | | CYCLOC | | 0 | - | 120 100 (27 000) | 477 (68.2) | .05 | 15 300 | 148 100 (33 300) | 588 (84.3) | |
| L3-1-40 | | 3.28 (.129) | 75.0 (2.953) | | 3.0 (.12) | | | | | 0 | - | 120 100 (27 000) | 489 (70.9) | | 10 ³ | 133 400 (30 000) | 543 (78.7) | |
| L3-1-41 | | 3.30 (.130) | 75.2 (2.960) | | 3.3 (.13) | | | PRELOAD CYCLOC | | 133 400 (30 000) | 538 (78.0) | 120 100 (27 000) | 484 (70.2) | | 15 300 | 141 400 (31 800) | 569 (82.6) | |
| L3-1-42 | | 3.38 (.133) | 75.2 (2.960) | | 3.0 (.12) | | | | | 133 400 (30 000) | 525 (76.1) | 120 100 (27 000) | 473 (68.6) | | 10 ³ | 145 400 (32 700) | 573 (83.1) | |
| L3-2-2 | L3 | 2.92 (.115) | 75.2 (2.959) | 1/8 FP SLIT | 3.0 (.12) | | | STATIC | | 0 | - | NONE | - | - | - | 143 300 (32 300) | 520 (75.1) | |
| L3-2-3 | | 2.97 (.117) | 74.9 (2.949) | | 3.0 (.12) | | | PRELOAD STATIC | | 102 800 (23 100) | 462 (67.0) | NONE | - | - | - | 107 200 (24 100) | 481 (69.8) | |

LAMINATE L3 [0/430/0/-30/0]2s * PLY OF 5-CLASS IN SPEC L3-1-X

GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | | RESIDUAL STATIC | | REMARKS |
|-----------|-------|--------------------------------|-----------------------|----------------|-----------------------|----------------------|-------------------------------|------------------|-----------------------------|-------------------|--------------------------------------|--------------------------|---|-----|--------|--------------------|--------------------------------------|---------------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | STRESS MN/m ² (KSI) | |
| L3-1-19 | L3 | 3.28 (.128) | 75.0 (2.952) | 5/8 HP SLIT | None (.00) | 0 | 1.5 (.06) | STATIC | RT | 155200 (34900) | 632 (91.6) | NONE | - | - | - | 200600 (45100) | 791 (114.7) | FAVOR DORWIN PRELIM |
| L3-1-20 | | 3.28 (.128) | 75.0 (2.952) | | 16.5 (.65) | 0 | | STATIC | | 0 | - | NONE | - | - | - | - | - | FAVOR DORWIN PRELIM |
| L3-1-51 | | 3.30 (.130) | 75.0 (2.952) | | 16.5 (.65) | 0 | | CYCCLIC | | 0 | - | 125900 (28200) | 508 (72.7) | .05 | 259986 | - | - | FAVOR DORWIN PRELIM |
| L3-1-60 | | 3.40 (.134) | 75.1 (2.955) | | 15.7 (.62) | 0 | | | | 0 | - | 125900 (28200) | 403 (57.5) | | 13 | 17300 (40300) | 702 (101.8) | FAVOR DORWIN PRELIM |
| L3-1-61 | | 2.33 (.131) | 75.0 (2.952) | | 14.7 (.58) | 0 | | PRELIM CYCLIC | | 137100 (31400) | 560 (81.2) | 125900 (28200) | 504 (72.1) | | 450516 | - | - | FAVOR DORWIN PRELIM |
| L3-1-62 | | 2.33 (.131) | 75.0 (2.952) | | 14.5 (.57) | 0 | | | | 137100 (31400) | 559 (81.1) | 125900 (28200) | 504 (72.1) | | 1057 | 165900 (37300) | 465 (66.4) | FAVOR DORWIN PRELIM |
| L3-2-6 | L3 | 2.87 (.113) | 75.0 (2.952) | 5/8 HP SLIT | 17.0 (.67) | 0 | 1.5 (.06) | PRELIM | | 0 | - | NONE | - | - | - | 121000 (27200) | 543 (78.8) | FAVOR DORWIN PRELIM |
| L3-2-7 | | 2.95 (.116) | 75.0 (2.952) | | 15.7 (.62) | 0 | | PRELIM STATIC | | 109000 (24500) | 493 (71.5) | NONE | - | - | - | 27700 (6200) | 578 (83.8) | FAVOR DORWIN PRELIM |

LAMINATE L3 [(0/+30/0/-30/0)₂]_S * MAX OF S-GLOSS IN SPEC L3-1-X
GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | | RESIDUAL STATIC | | REMARKS |
|-----------|-------|--------------------------------|-----------------------|----------------|-----------------------|----------------------|-------------------------------|-------------------|-----------------------------|-------------------|--------------------------------------|--------------------------|---|-----|-----------------|--------------------|--------------------------------------|-----------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (1b) | STRESS MN/m ² (KSI) | MAX LOAD N (1b) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (1b) | STRESS MN/m ² (KSI) | |
| L3-1-15 | L3 | 3.38 (.133) | 75.1 (2.956) | 3/8 HP SLIT | 9.9 (.39) | 0 | 1.5 (.06) | STATIC | RT | 0 | - | NONE | - | - | - | 182400 (40550) | 711 (102.1) | FATIGUE FAILURE |
| L3-1-16 | | 3.20 (.126) | 75.0 (2.954) | | 9.9 (.39) | 0 | 1.5 (.06) | PRELOAD STATIC | | 162400 (36500) | 676 (98.1) | NONE | - | - | - | 167000 (37550) | 696 (100.9) | FATIGUE FAILURE |
| L3-1-51 | | 3.20 (.130) | 75.1 (2.957) | | 10.4 (.41) | 0 | | CYCLIC | | 0 | - | 135200 (30400) | 545 (79.1) | 0.5 | 875512 | - | - | FATIGUE FAILURE |
| L3-1-52 | | 3.40 (.134) | 75.1 (2.957) | | 10.7 (.42) | 0 | | | | 0 | - | 135200 (30400) | 529 (76.7) | | 10 ³ | 177400 (40000) | 696 (100.9) | FATIGUE FAILURE |
| L3-1-53 | | 3.28 (.129) | 75.1 (2.958) | | 10.2 (.40) | 0 | | PRELOAD CYCLIC | | 130300 (33800) | 611 (88.6) | 135200 (30400) | 549 (79.1) | | 17100 | - | - | FATIGUE FAILURE |
| L3-1-54 | | 3.35 (.132) | 75.1 (2.958) | 3/8 HP SLIT | 9.4 (.37) | | | CYCLIC | | 0 | - | 130000 (20900) | 369 (53.5) | | 10 ⁵ | 114300 (25700) | 454 (65.8) | FATIGUE FAILURE |
| L3-1-11 | L3 | 3.38 (.133) | 75.1 (2.955) | 1/8 HP SLIT | 3.0 (.12) | 0 | 1.5 (.06) | STATIC | | 0 | - | NONE | - | - | - | 190400 (42800) | 751 (108.9) | FATIGUE FAILURE |
| L3-1-12 | | 3.22 (.127) | 75.2 (2.962) | | 3.0 (.12) | 0 | | PRELOAD STATIC | | 171300 (38500) | 705 (102.3) | NONE | - | - | - | 181000 (40700) | 746 (108.2) | FATIGUE FAILURE |
| L3-1-43 | | 3.22 (.127) | 75.2 (2.960) | | 3.0 (.12) | 0 | | CYCLIC | | 0 | - | 153900 (34600) | 634 (92.0) | 0.5 | 7,177 | - | - | FATIGUE FAILURE |
| L3-1-44 | | 3.30 (.130) | 75.1 (2.958) | | 3.0 (.12) | 0 | | | | 0 | - | 153900 (34600) | 621 (90.0) | | 10 ³ | 183700 (41300) | 741 (107.4) | FATIGUE FAILURE |
| L3-1-45 | | 3.30 (.130) | 74.6 (2.937) | | 3.0 (.12) | 0 | | PRELOAD CYCLIC | | 171200 (38500) | 695 (100.8) | 153900 (34600) | 625 (90.6) | | 280400 | - | - | FATIGUE FAILURE |
| L3-1-46 | | 3.38 (.133) | 74.6 (2.938) | | 3.0 (.12) | 0 | | | | 171200 (38500) | 679 (98.5) | 153900 (34600) | 610 (88.5) | | 10 ³ | 191700 (43100) | 761 (110.3) | FATIGUE FAILURE |

L3 LAMINATE L3 [(0/+30/0/-30/0)₂]_s x 24 OF 5-GLASS IN SPEC L3-1-X
 12 GROSS SECTION STRESS

| SPEC. NO. | LAYUP | THICK- NESS mm (INCH) | WIDTH mm (INCH) | FLAW TYPE | FLAW LENGTH | | FLAW DEPTH mm (INCH) | TEST TYPE | TEST TEMP. °K (°F) | PRELOAD | | CYCLIC LOADING | | | RESIDUAL STATIC | | REMARKS | |
|-----------|-------|--------------------------------|-----------------------|-----------|-----------------------|----------------------|----------------------------|-----------------------------|--------------------------|-------------------|--------------------------------------|--------------------------|---|-----|-----------------|-------------------|----------------|--------------------------------------|
| | | | | | FRONT mm (INCH) | BACK mm (INCH) | | | | LOAD N (lb) | STRESS MN/m ² (KSI) | MAX LOAD N (lb) | MAX STRESS MN/m ² (KSI) | R | CYCLES | LOAD N (lb) | | STRESS MN/m ² (KSI) |
| 13-1-1 | D → | 3.45 (.136) | 75.2 (2.960) | NONE | 0 | 0 | 0 | Static PRELOAD STATIC | RT | 0 | - | - | - | - | - | 240320 (54000) | 924 (134.1) | FATIGUE FAILURE |
| 13-1-2 | | 3.32 (.131) | 75.1 (2.957) | | 0 | 0 | 0 | | | 216320 (48600) | 86.5 (12.5.5) | 0 | - | - | - | 227760 (51200) | 912 (132.2) | |
| 13-1-21 | | 3.30 (.130) | 75.1 (2.958) | | 0 | 0 | 0 | CYCLIC | | 0 | - | 153900 (34600) | 621 (90.5) | 0.5 | 122284 | - | - | |
| 13-1-22 | | 3.35 (.132) | 75.0 (2.951) | | 0 | 0 | 0 | | | 0 | - | 153900 (34600) | 612 (89.1) | | 10 ³ | 234960 (52800) | 934 (135.4) | |
| 13-1-23 | | 3.35 (.132) | 75.1 (2.958) | | 0 | 0 | 0 | PRELOAD CYCLIC | | 216300 (48600) | 87.1 (12.6.3) | - | - | - | - | - | - | |
| 13-1-24 | | 3.25 (.128) | 75.1 (2.958) | | 0 | 0 | 0 | | | 212200 (47700) | 86.9 (12.6.0) | - | - | - | - | - | - | |

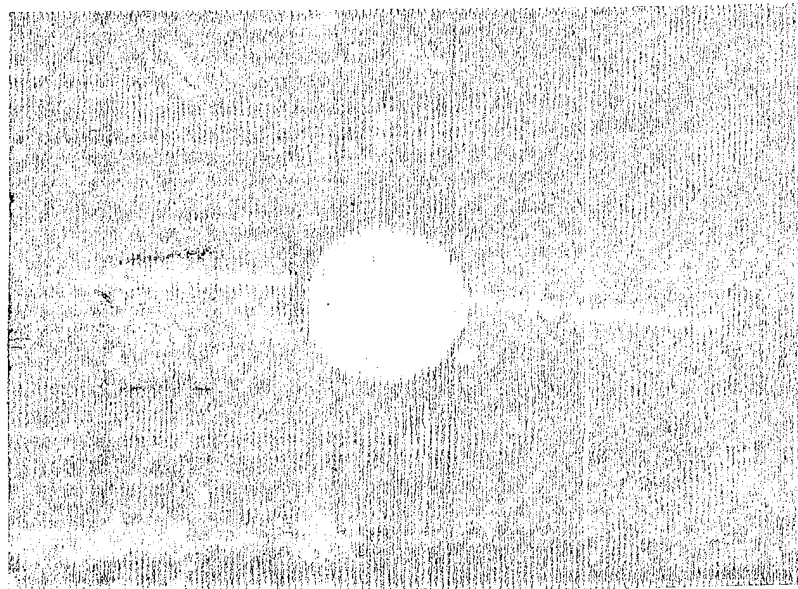
13 LAMINATE L3 [(0/+30/0/30/0)₂]_s K DLY OF S-GLOSS IN SPEC L3-1-X

13 GROSS SECTION STRESS

APPENDIX B

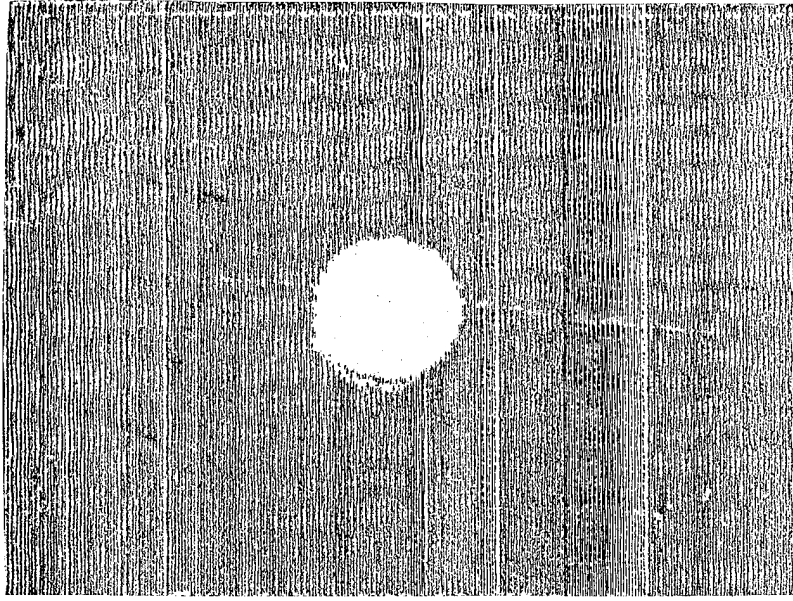
ULTRASONIC INSPECTION DATA

This appendix contains copies of the ultrasonic C-scan records that were developed for the test specimens. The records are identified by the test specimen number, the defect code and a brief description of the point in the test sequence the inspection was made. For many of the test specimens, ultrasonic inspection was performed several times during the test showing the progressive development of the damage.



BEFORE TEST

SPECIMEN NUMBER LI-5-6
5/8 FP HOLE

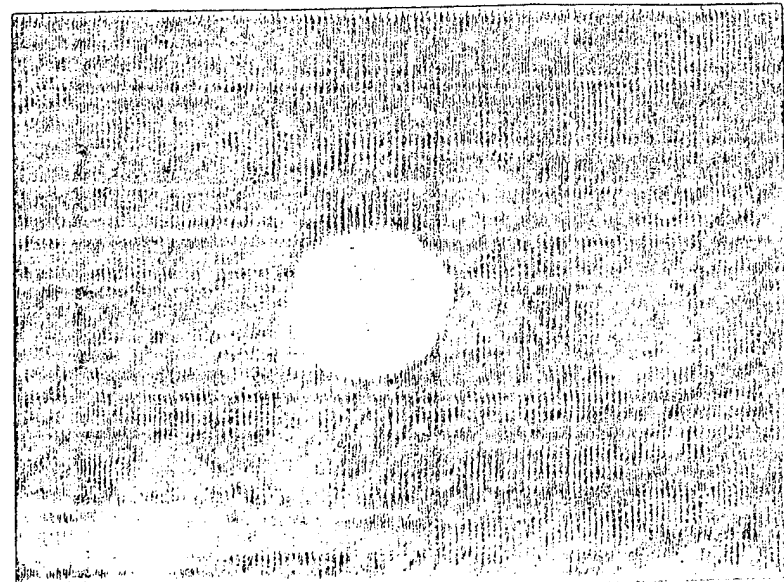


AFTER CYCLIC TEST

10³ CYCLES

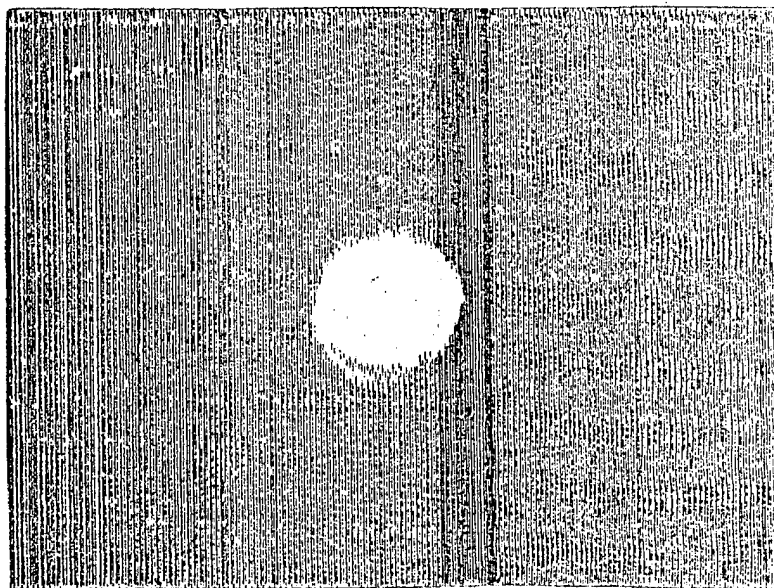
NO PRELOAD

AFTER PRELOAD

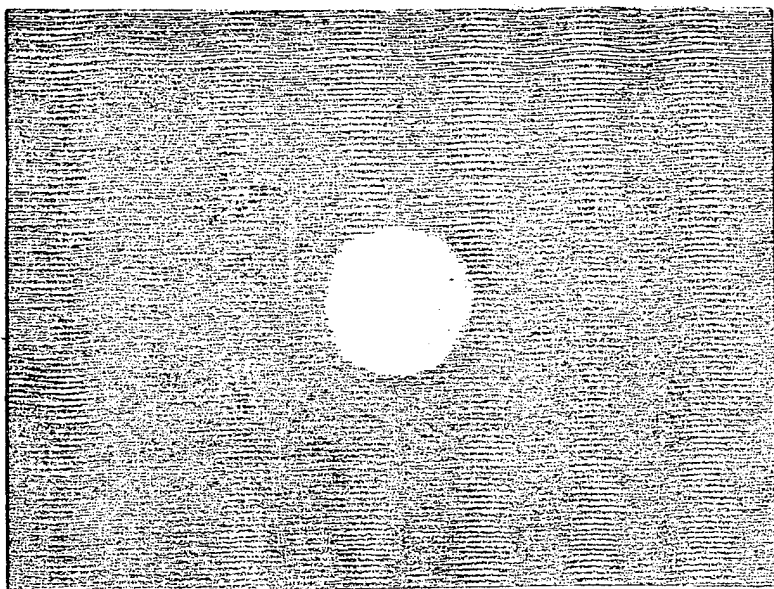


BEFORE TEST

SPECIMEN NUMBER LI-5-9
5/8 FP HOLE



AFTER PRELOAD

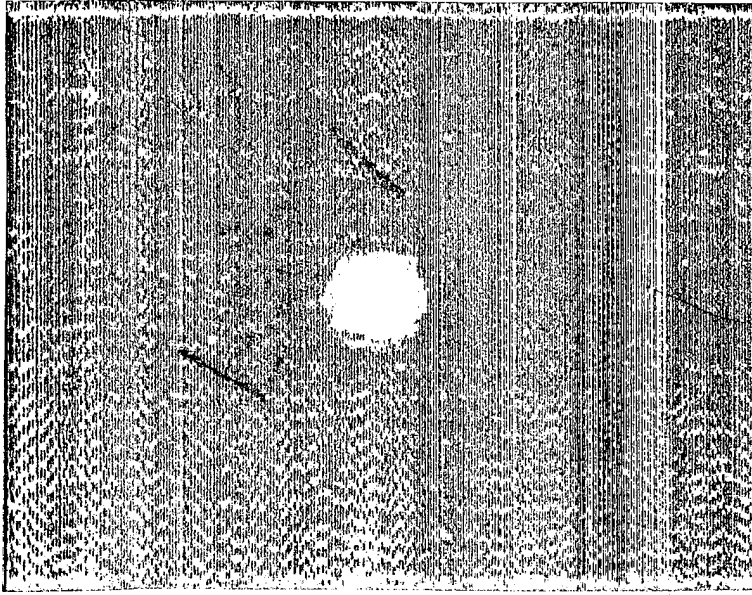


AFTER CYCLIC TEST

10^5 CYCLES

NOT INSPECTED

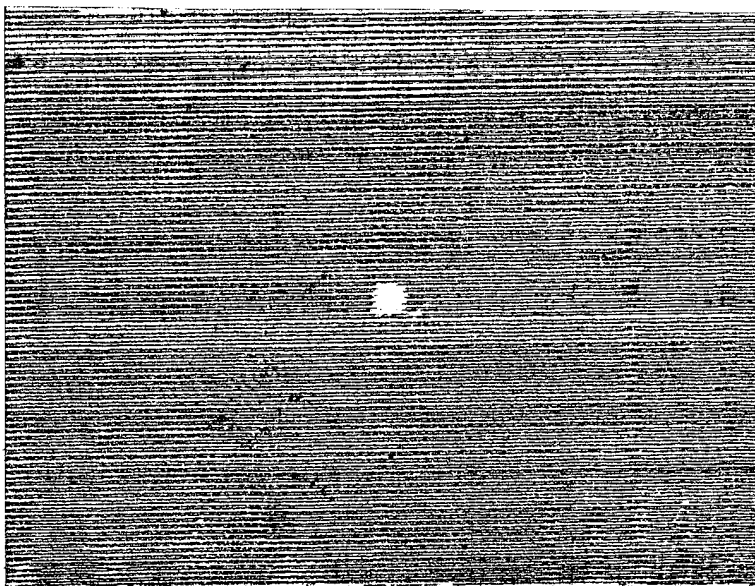
NO PRELOAD



BEFORE TEST
SPECIMEN NUMBER LI-4-12
3/8 FP HOLE

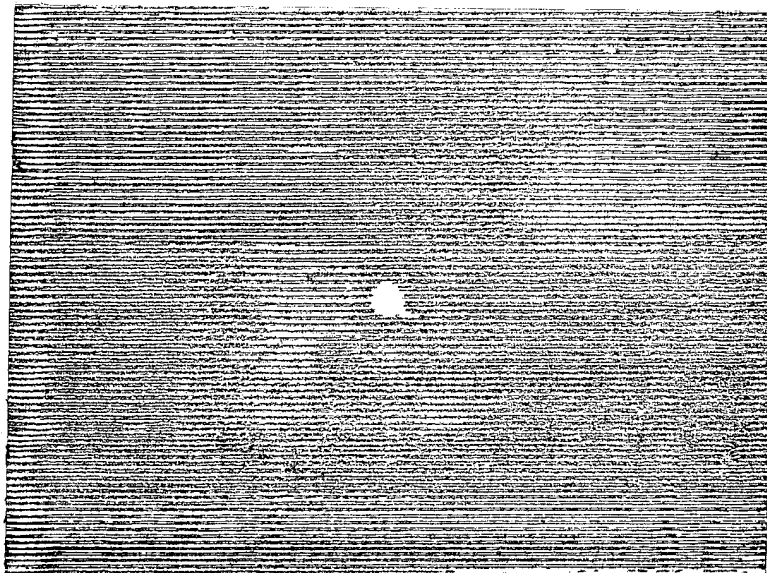
AFTER CYCLIC TEST
10⁵ CYCLES





NO PRELOAD

AFTER 10^3 CYCLES
SPECIMEN NUMBER LI-4-1
1/8 FULL PENETRATION HOLE

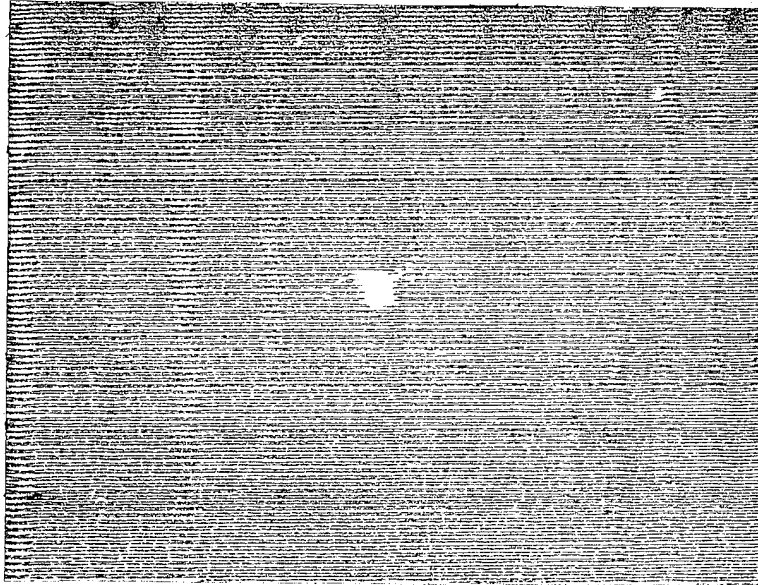


PRELOADED

AFTER 10^3 CYCLES

SPECIMEN NUMBER LI-4-3

1/8 FULL PENETRATION HOLE

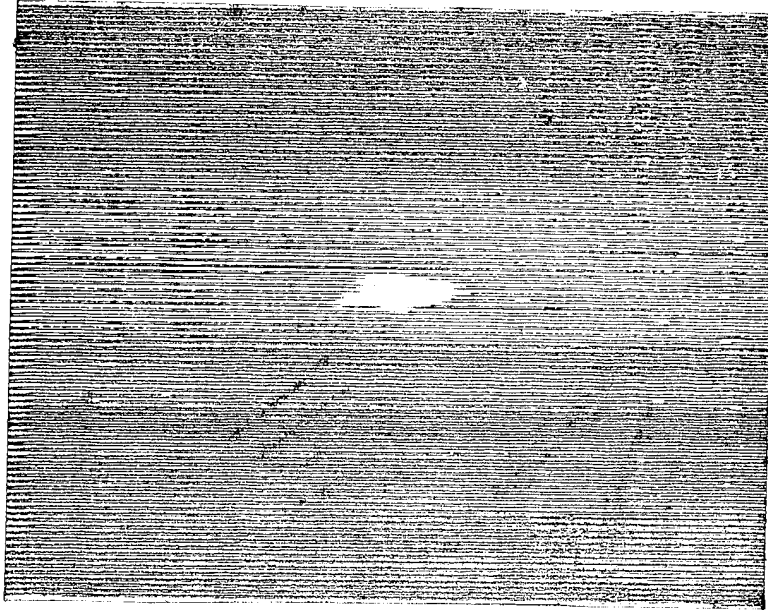


PRELOADED

AFTER 10^5 CYCLES

SPECIMEN NUMBER LI-4-4

1/8 FULL PENETRATION HOLE

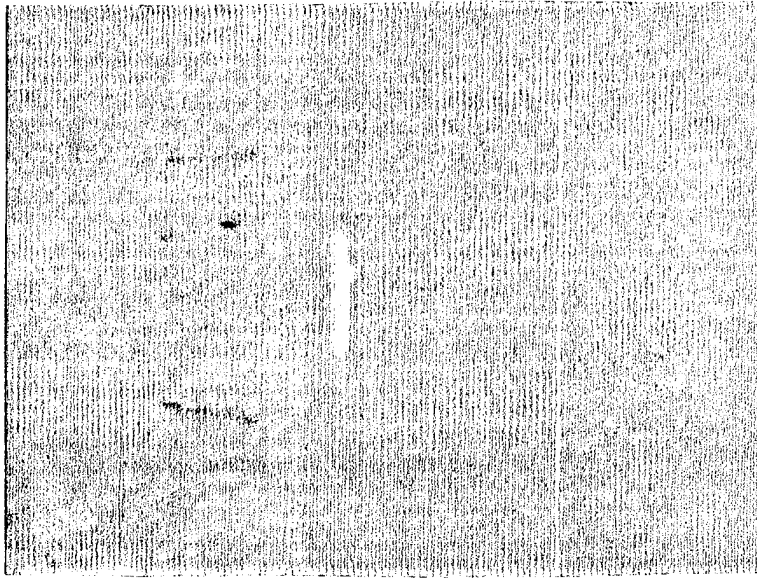


PRELOADED

AFTER 1.5×10^6 CYCLES

SPECIMEN NUMBER LI-4-2

1/8 FULL PENETRATION HOLE

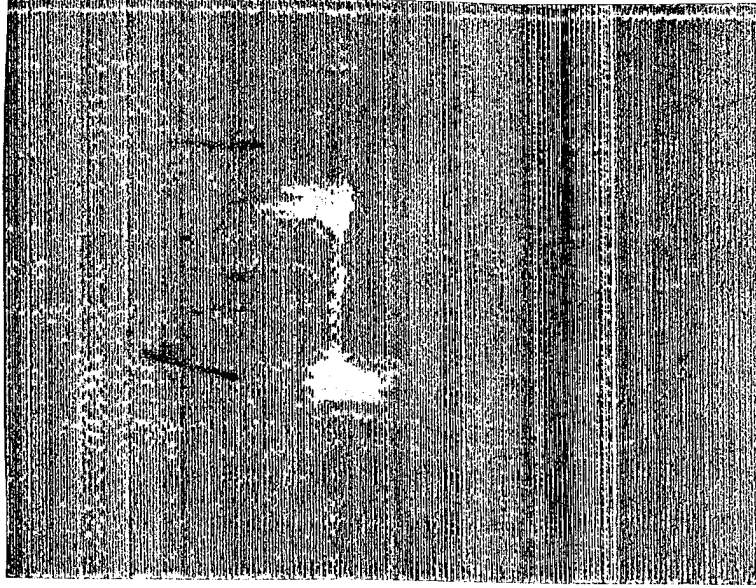


BEFORE TEST

SPECIMEN NUMBER LI-7-11

5/8 FP SLIT

NO PRELOAD

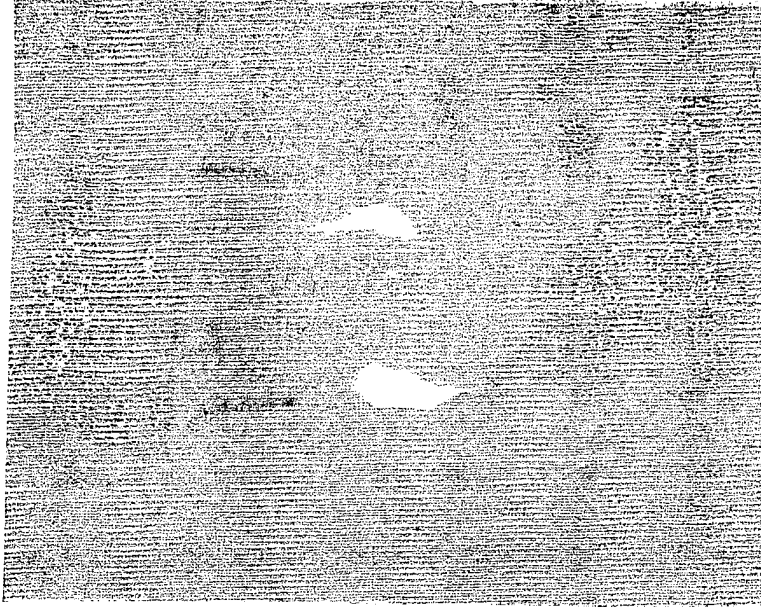


AFTER CYCLIC TEST

10³ CYCLES

NOT INSPECTED

NO PRELOAD

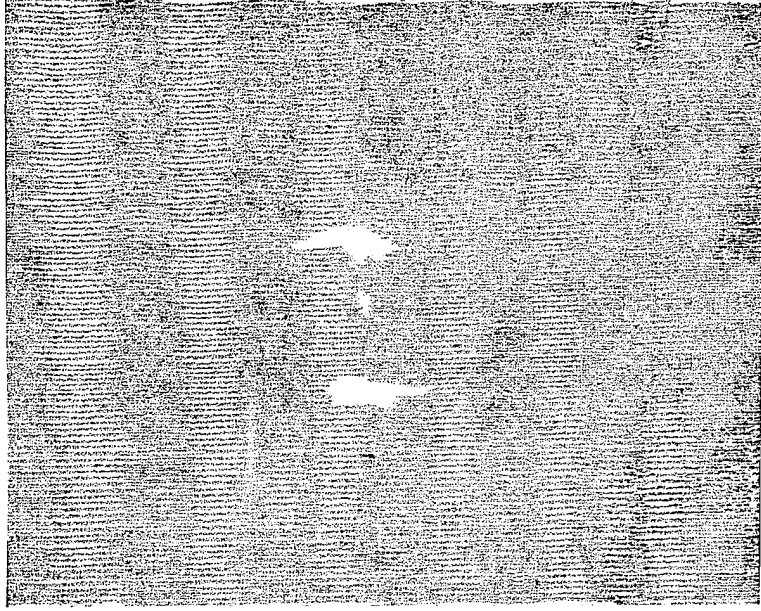


BEFORE TEST
SPECIMEN NUMBER LI-7-10
5/8 FP SLIT

AFTER CYCLIC TEST
10⁵ CYCLES

NOT INSPECTED

NO PRELOAD



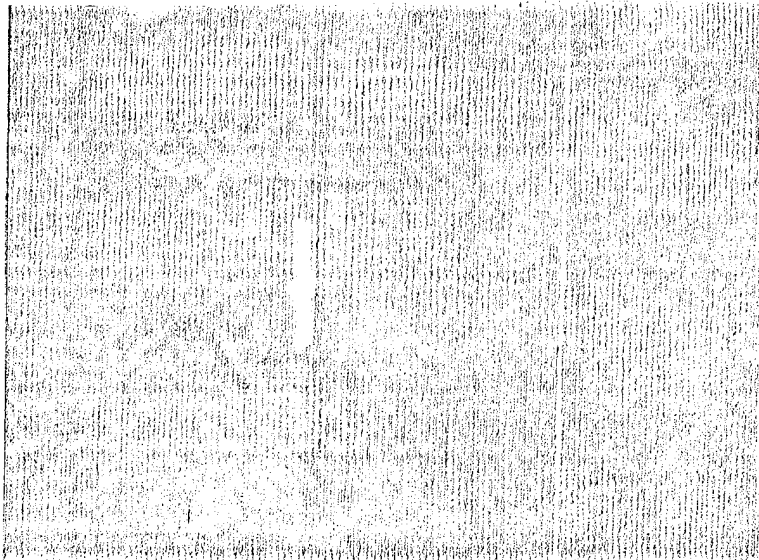
BEFORE TEST

SPECIMEN NUMBER LI-7-9

5/8 FP SLIT

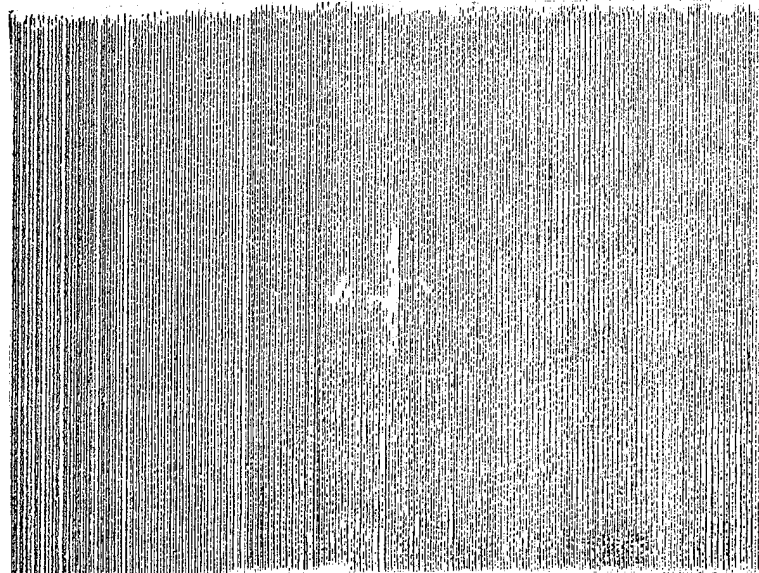
AFTER CYCLIC TEST

1.5×10^6 CYCLES

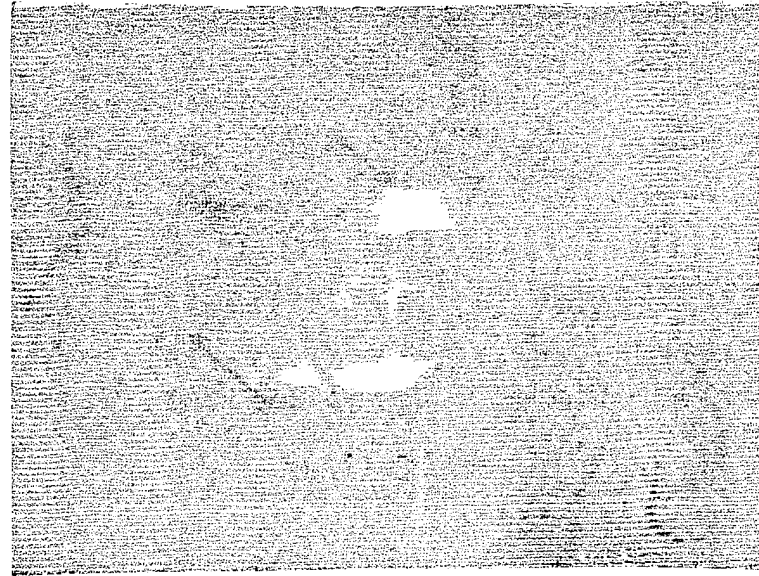


BEFORE TEST

SPECIMEN NUMBER LI-7-14
5/8 FP SLIT



AFTER PRELOAD

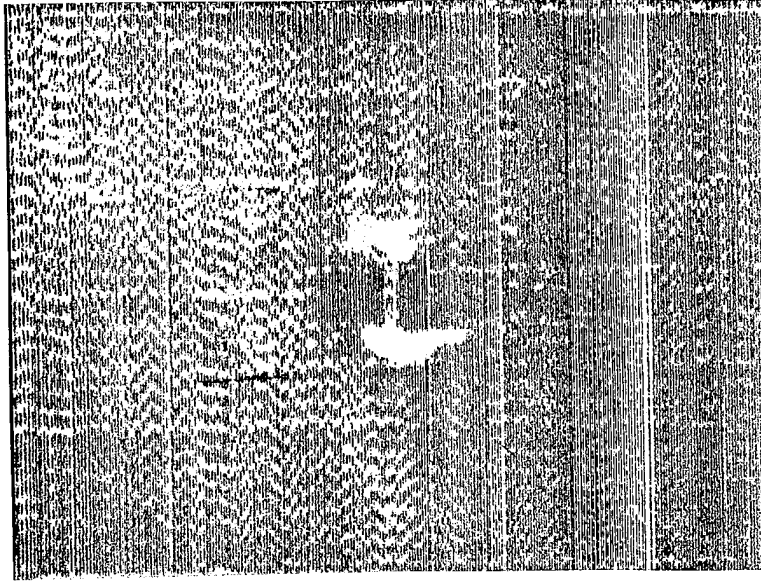


AFTER CYCLIC TEST

1.5×10^6 CYCLES

NOT INSPECTED

NOT INSPECTED



BEFORE TEST

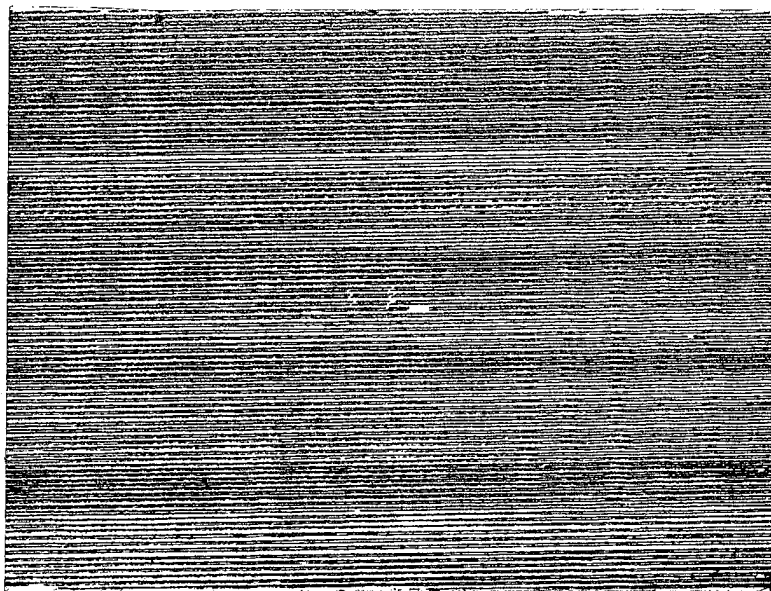
SPECIMEN NUMBER LI-7-7

3/8 FP SLIT

AFTER PRELOAD

AFTER CYCLIC TEST

10⁵ CYCLES

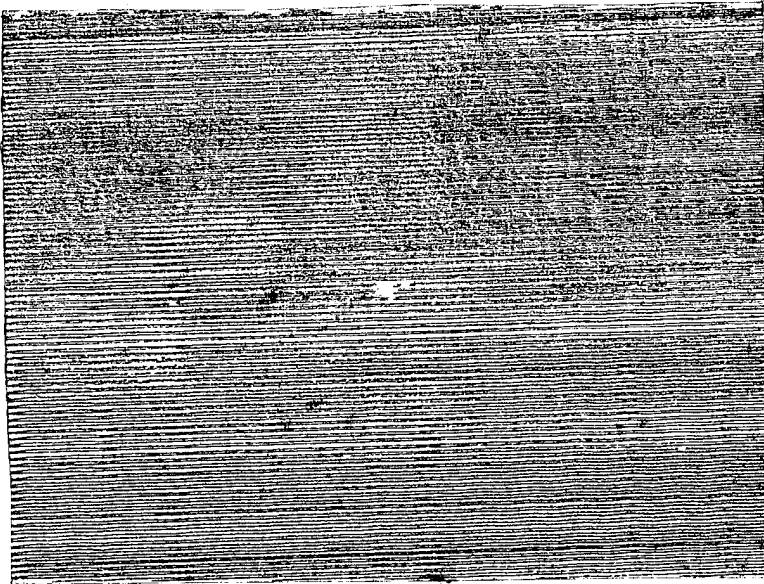


NO PRELOAD

AFTER 10^3 CYCLES

SPECIMEN NUMBER LI-6-4

1/8 FULL PENETRATION SLIT

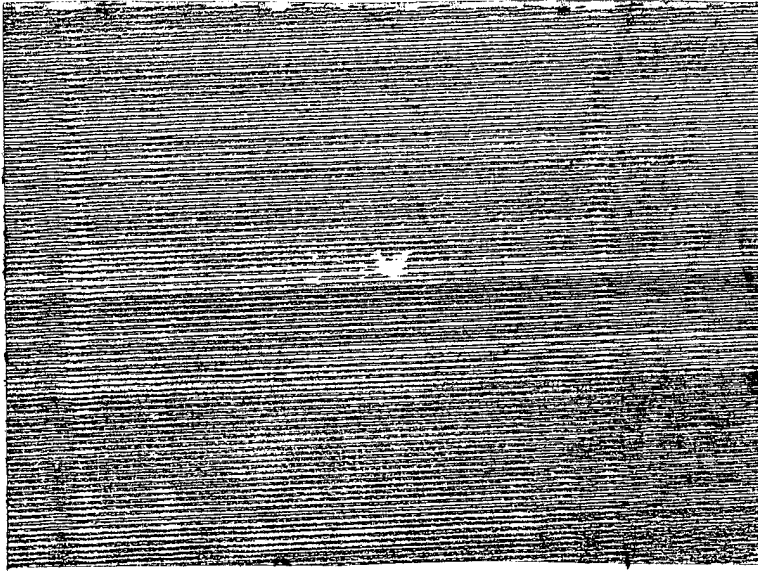


PRELOADED

AFTER 10^3 CYCLES

SPECIMEN NUMBER LI-6-7

1/8 FULL PENETRATION SLIT

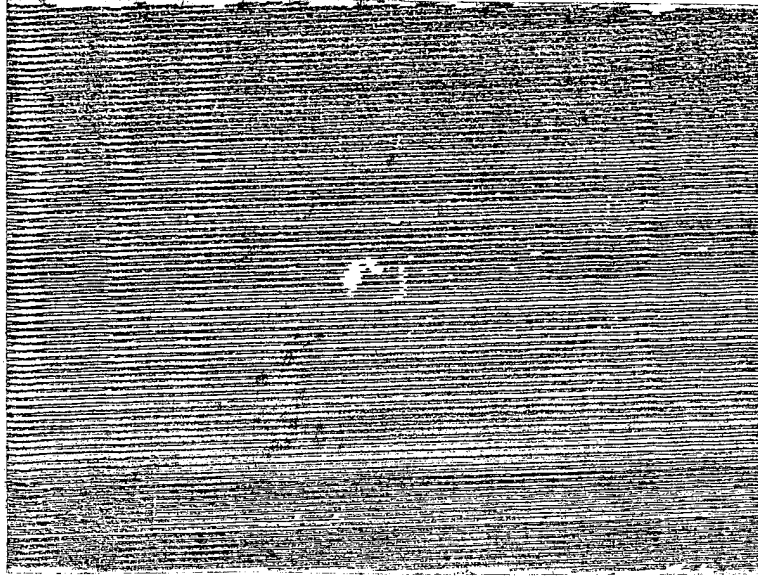


PRELOADED

AFTER 10^5 CYCLES

SPECIMEN NUMBER LI-6-8

1/8 FULL PENETRATION SLIT

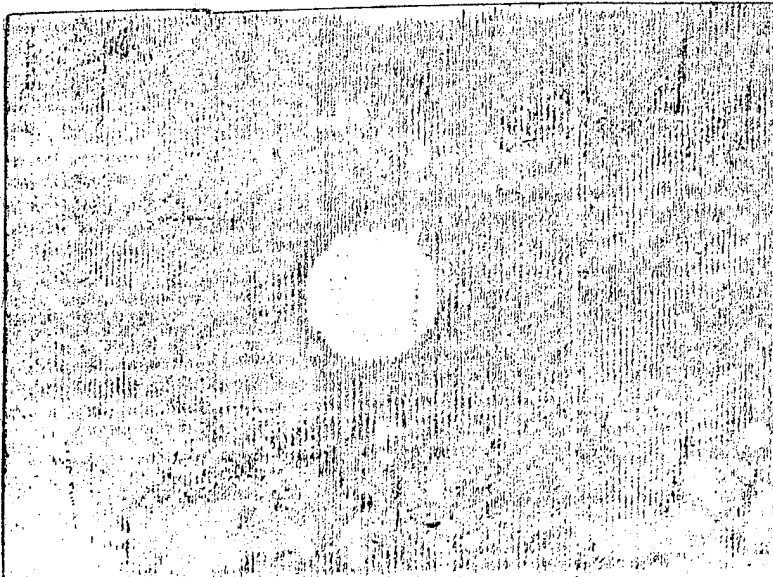


PRELOADED

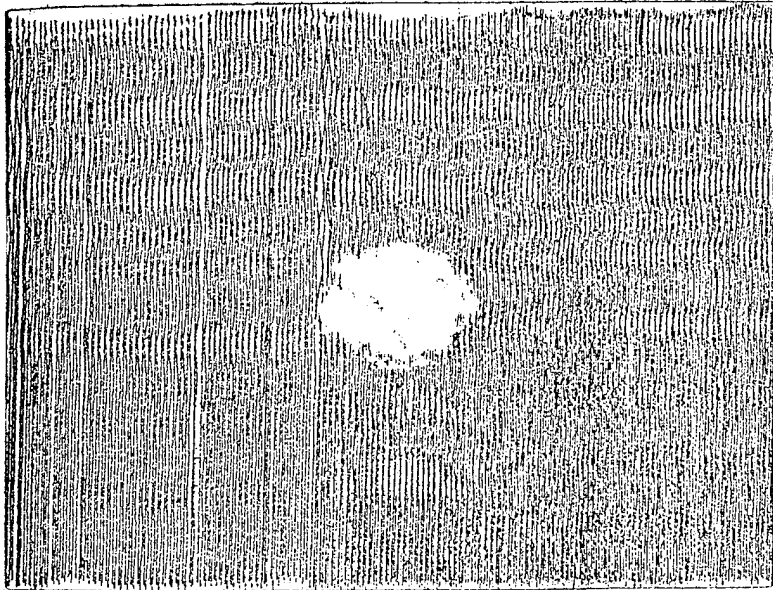
AFTER 1.5×10^6 CYCLES

SPECIMEN NUMBER LI-6-9

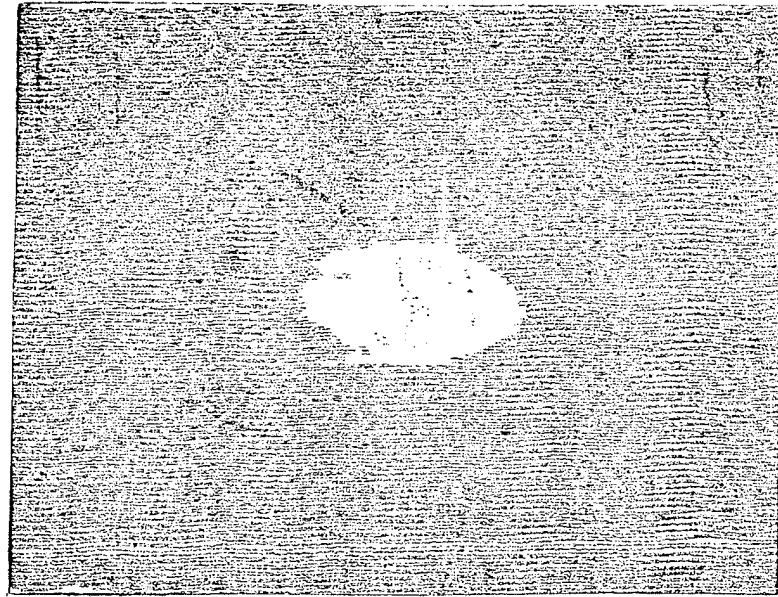
1/8 FULL PENETRATION SLIT



BEFORE TEST



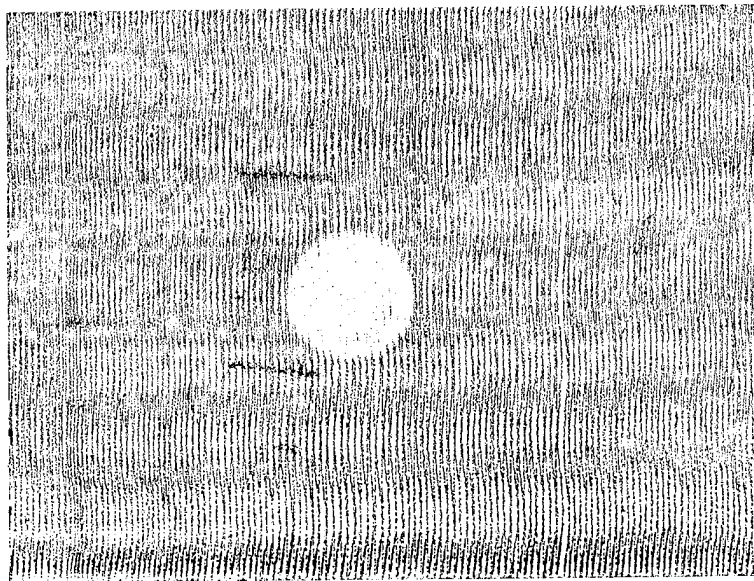
AFTER PRELOAD



AFTER 10^3 CYCLES

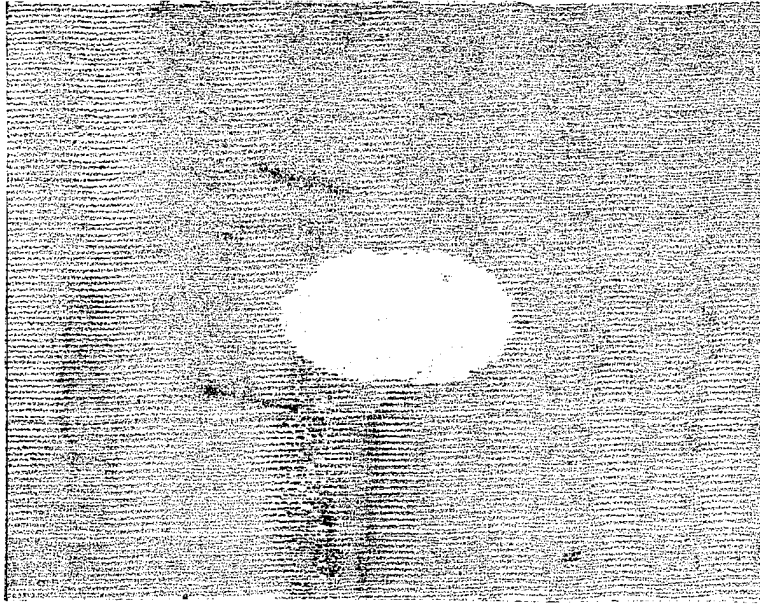
SPECIMEN NUMBER LI-6-3

5/8 HP HOLE

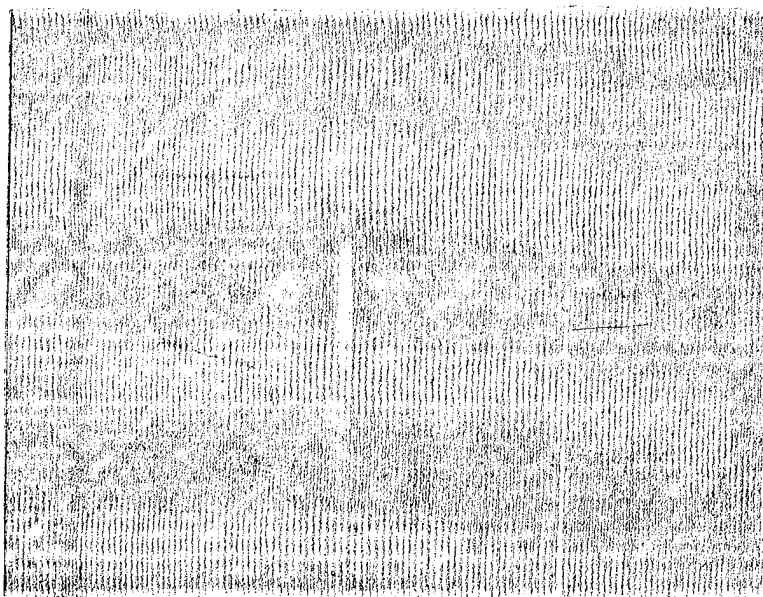


NO PRELOAD

BEFORE TEST
SPECIMEN NUMBER LI-5-12
5/8 HP HOLE

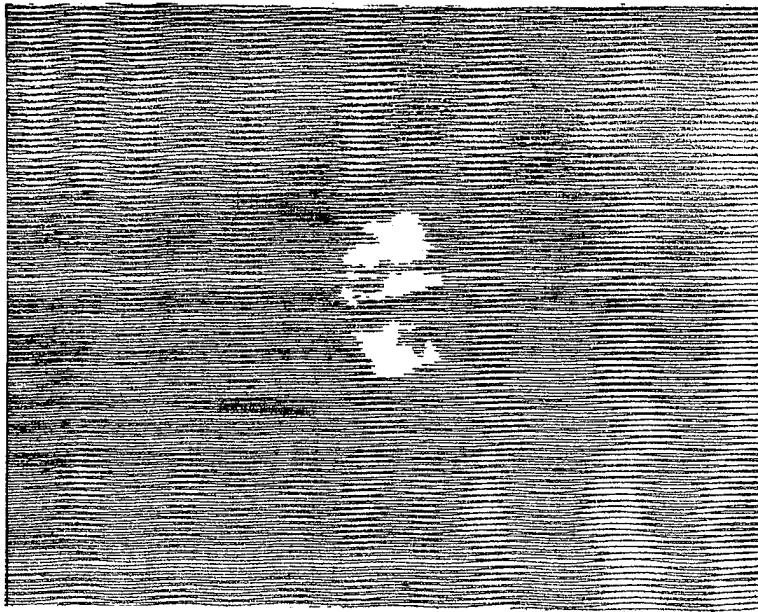


AFTER CYCLIC TEST
 10^3 CYCLES

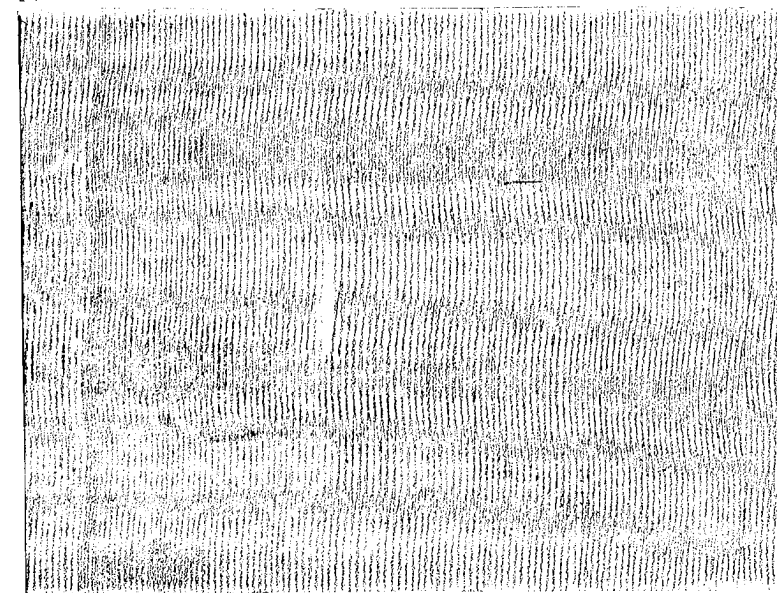


BEFORE TEST
SPECIMEN NUMBER LI-8-3
5/8 HP SLIT

NO PRELOAD



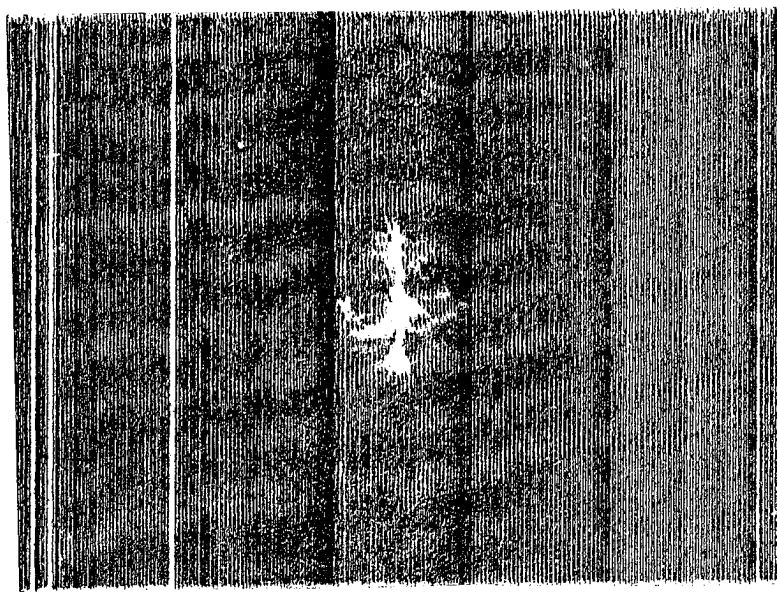
AFTER CYCLIC TEST
10³ CYCLES



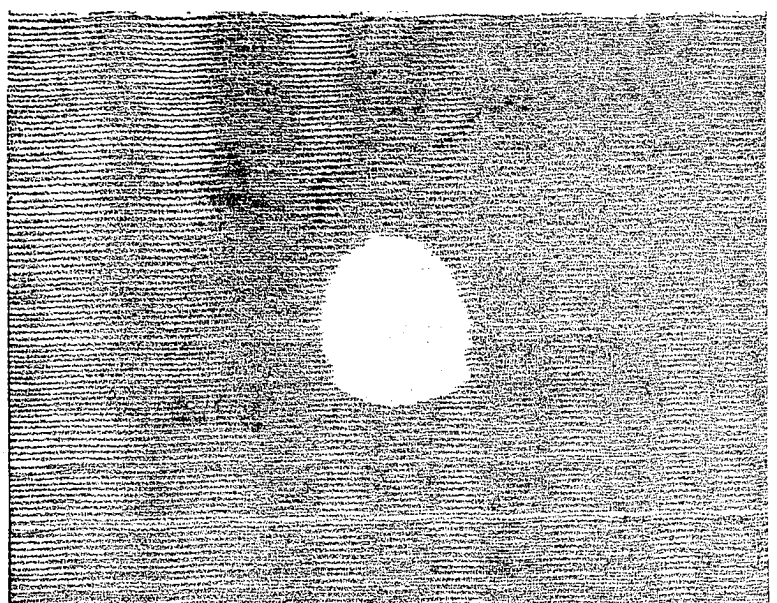
BEFORE TEST

SPECIMEN NUMBER LI-8-6

5/8 HP SLIT



AFTER PRELOAD

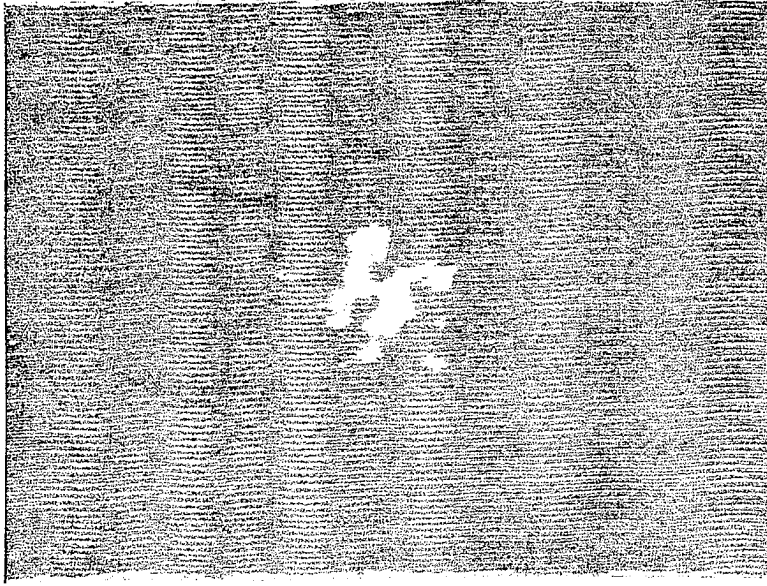


AFTER CYCLIC TEST

10³ CYCLES

NOT INSPECTED

NOT INSPECTED



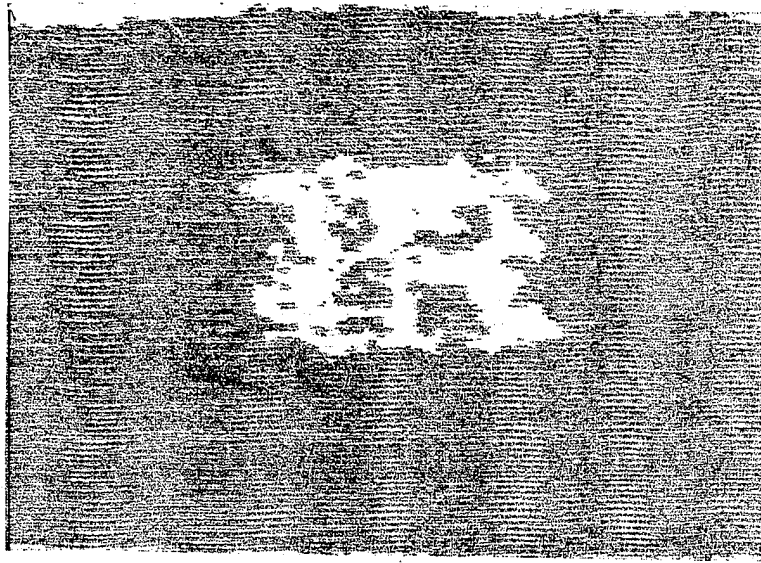
BEFORE TEST
SPECIMEN NUMBER LI-8-5
5/8 HP SLIT

AFTER PRELOAD

AFTER CYCLIC TEST
10⁵ CYCLES

NOT INSPECTED

NOT INSPECTED



BEFORE TEST

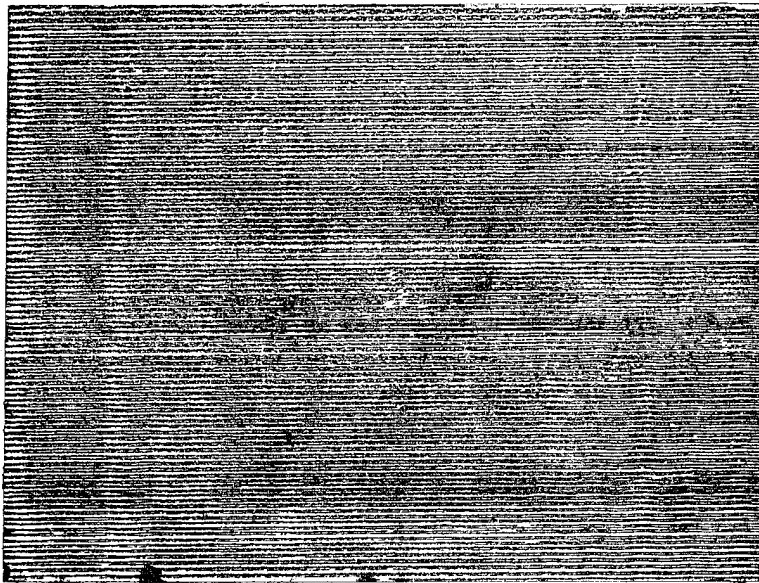
SPECIMEN NUMBER LI-8-4

5/8 HP SLIT

AFTER PRELOAD

AFTER CYCLIC TESTS

1.5 x 10⁶ CYCLES

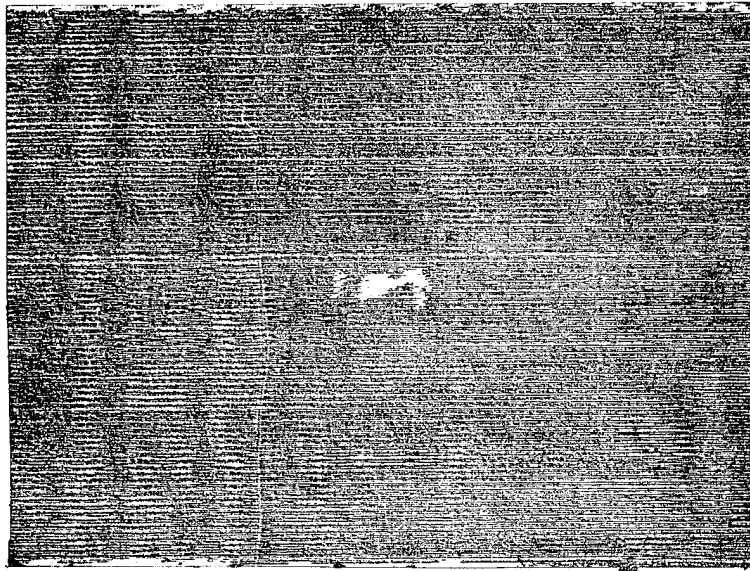


NO PRELOAD

AFTER 10³ CYCLES

SPECIMEN NUMBER LI-6-12

1/8 HALF PENETRATION SLIT

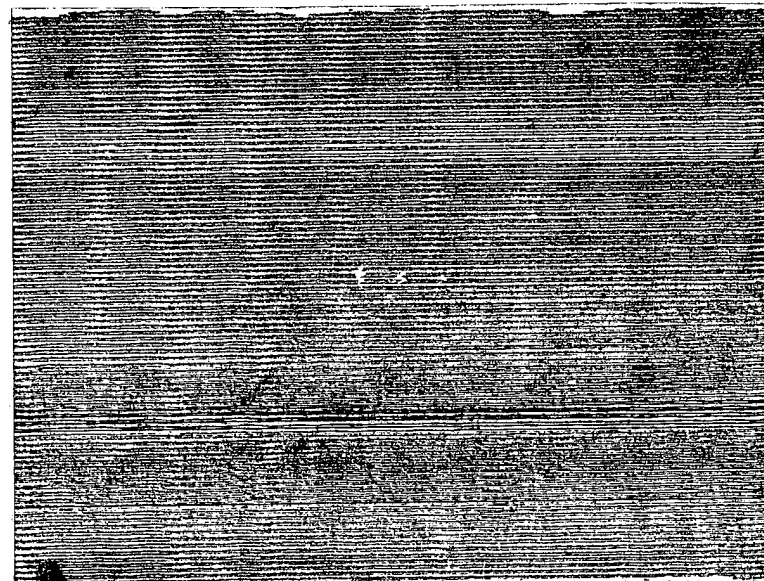


NO PRELOAD

AFTER 1.5 x 10⁶ CYCLES

SPECIMEN LI-7-1

1/8 HALF PENETRATION SLIT

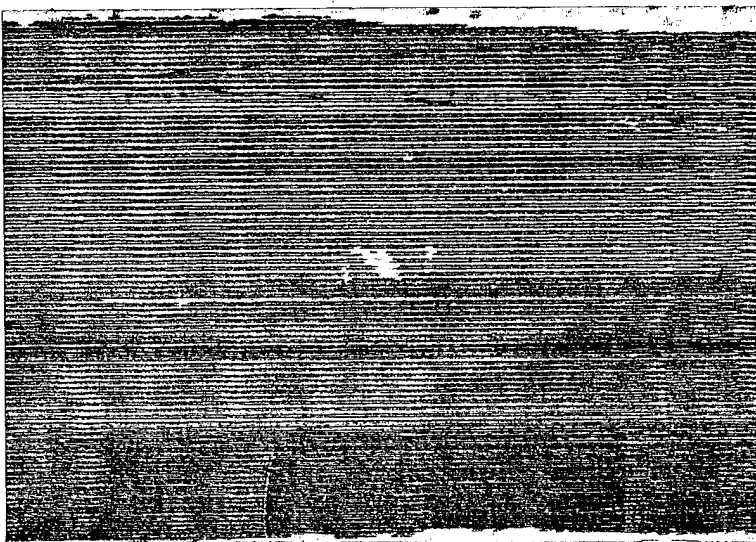


PRELOADED

10^3 CYCLES

SPECIMEN NUMBER LI-7-3

1/8 HALF PENETRATION SLIT

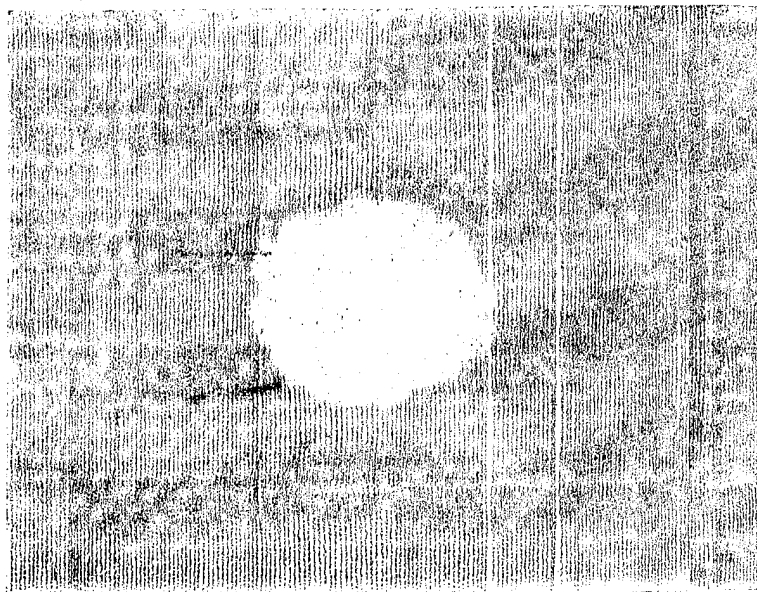


PRELOADED

10^5 CYCLES

SPECIMEN NUMBER LI-7-2

1/8 HALF PENETRATION SLIT

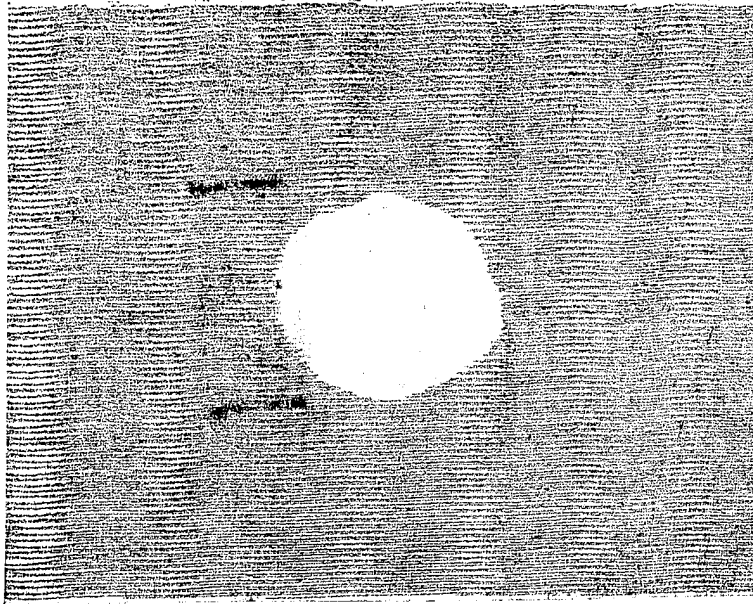


BEFORE TEST

SPECIMEN NUMBER LI-8-11

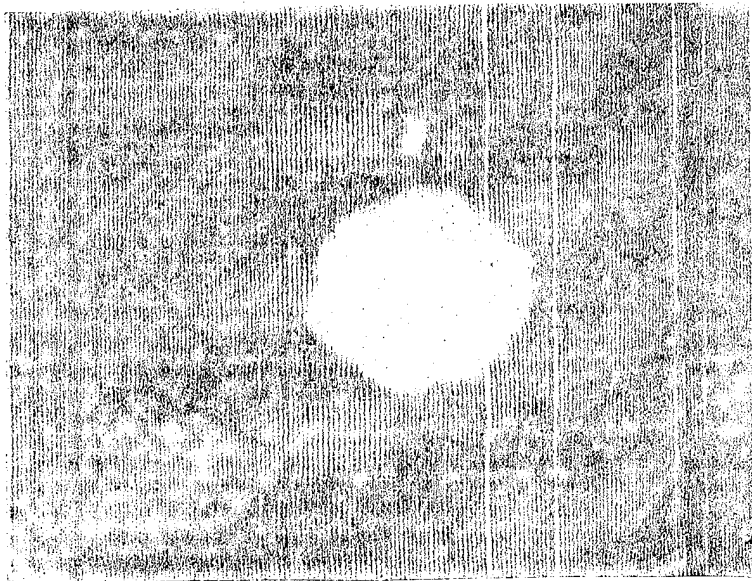
5/8 CSK HOLE

NO PRELOAD



AFTER CYCLIC TEST

10^3 CYCLES

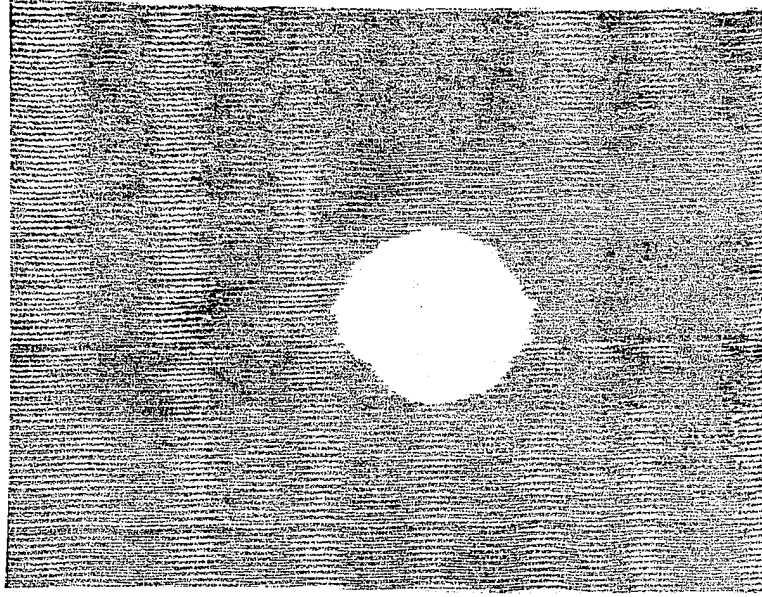


BEFORE TEST

SPECIMEN NUMBER LI-8-12

5/8 CSK HOLE

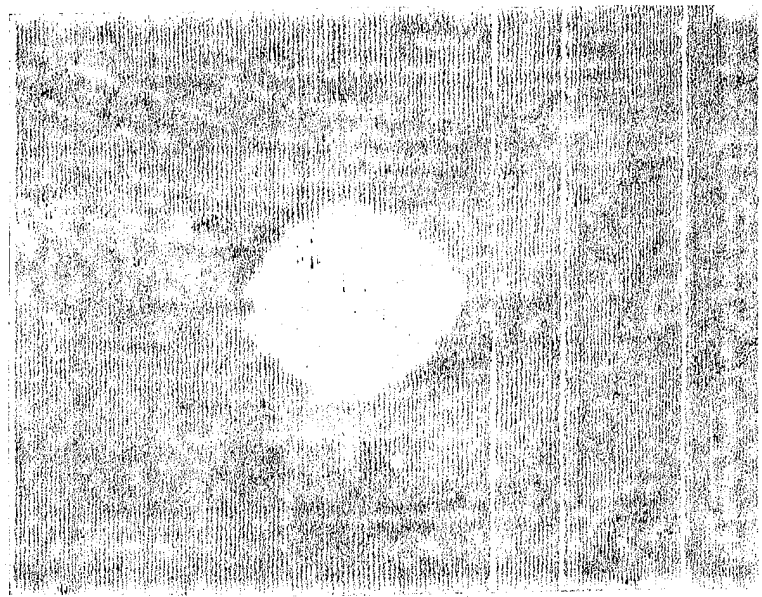
NO PRELOAD



AFTER CYCLIC TEST

1.5 x 10⁶ CYCLES

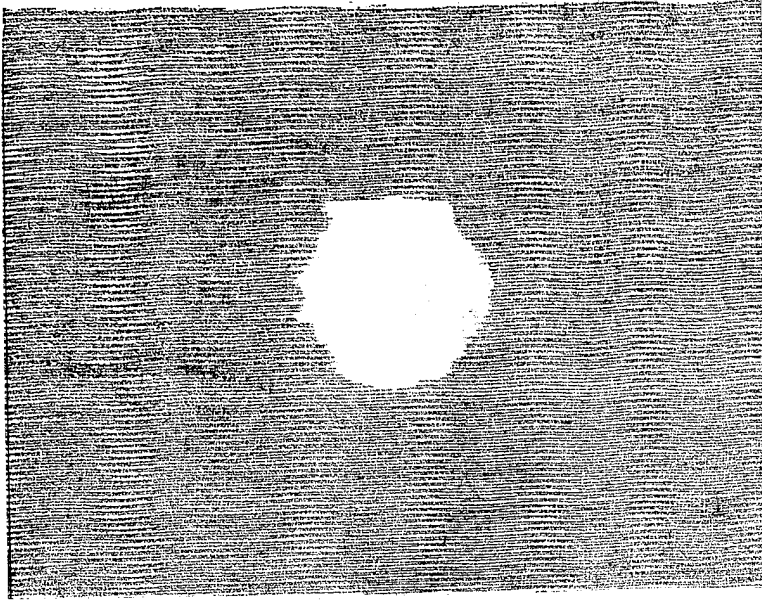
NOT INSPECTED



BEFORE TEST

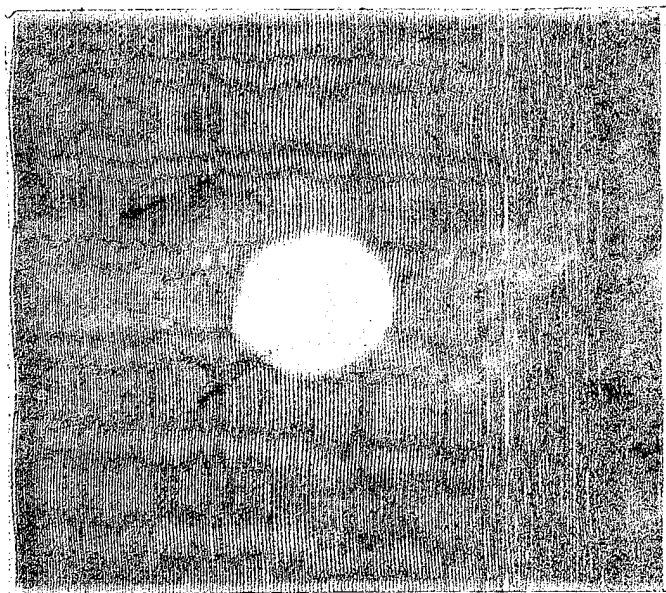
SPECIMEN NUMBER LI-8-14

5/8 CSK HOLE



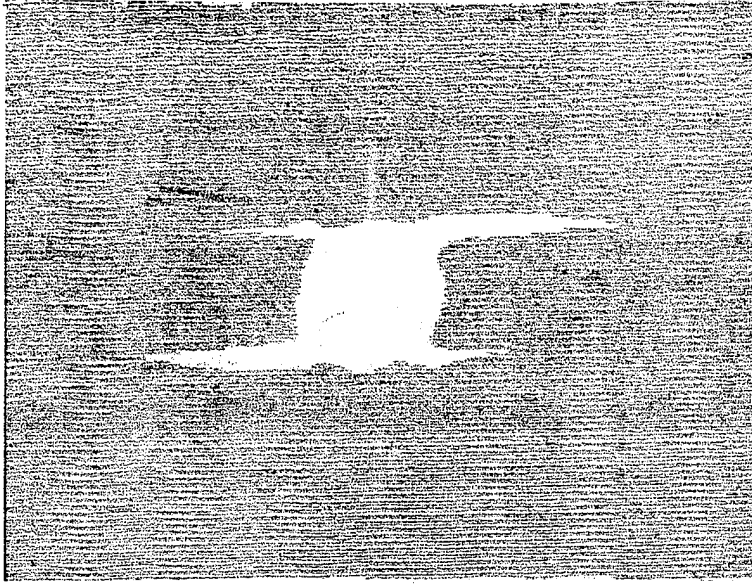
AFTER CYCLIC TEST

1.5×10^6 CYCLES

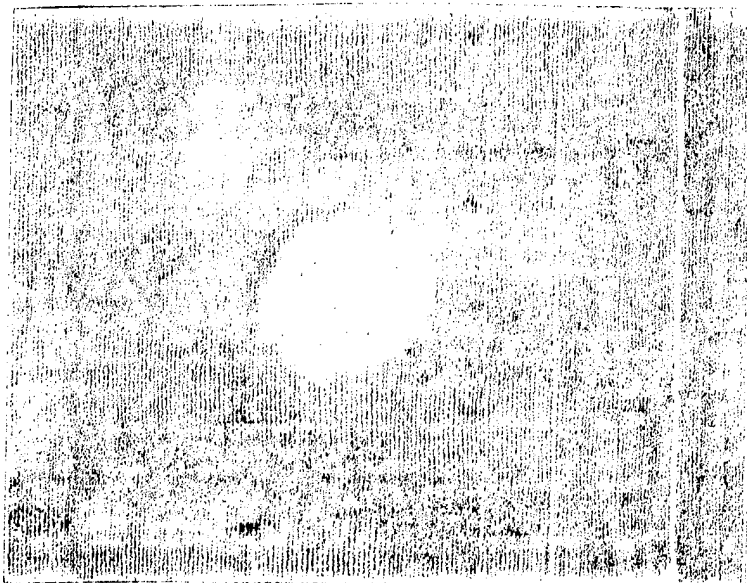


BEFORE TEST
SPECIMEN NUMBER L2-1-30
5/8 FP HOLE

NO PRELOAD



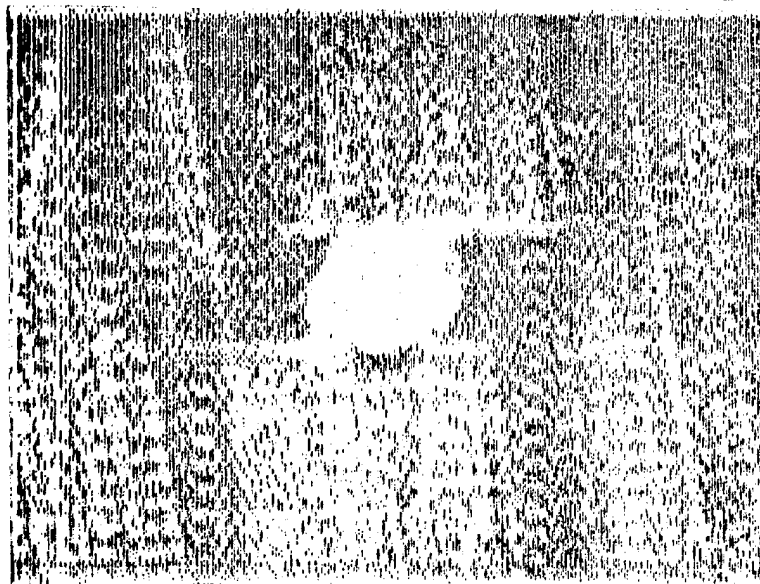
AFTER CYCLIC TEST
10³ CYCLES



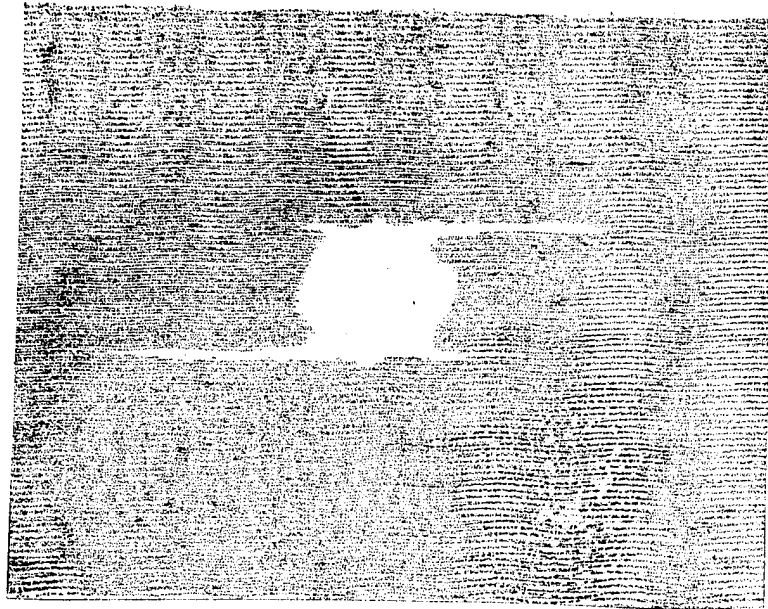
BEFORE TEST

SPECIMEN NUMBER L2-1-32

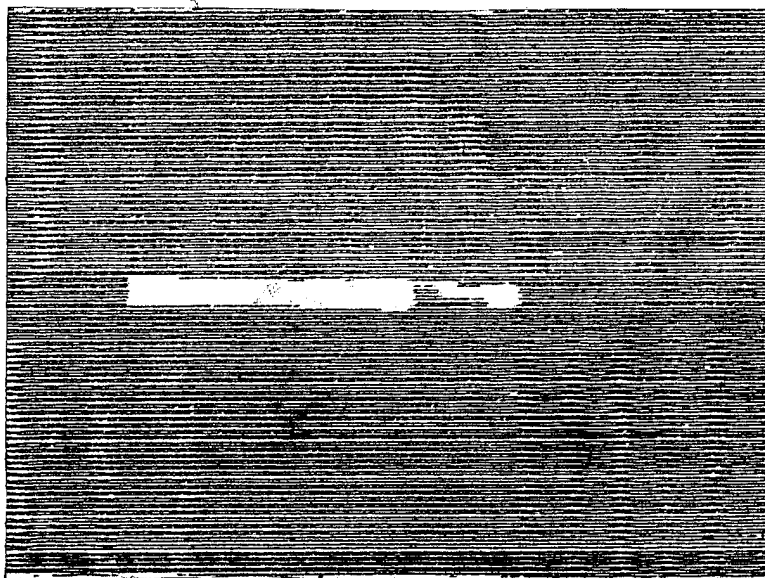
5/8 FP HOLE



AFTER PRELOAD



AFTER 10^3 CYCLES

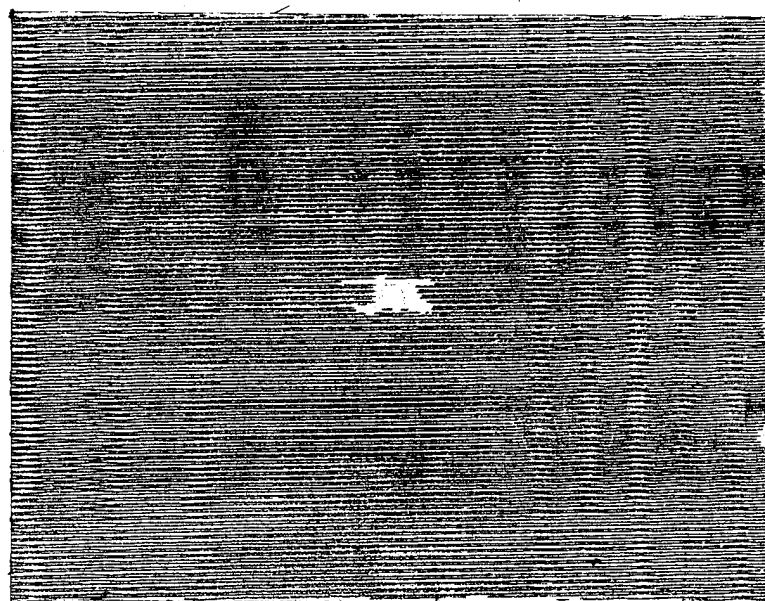


NO PRELOAD

10^3 CYCLES

1/8 FULL PENETRATION HOLE

SPECIMEN L2-1-26

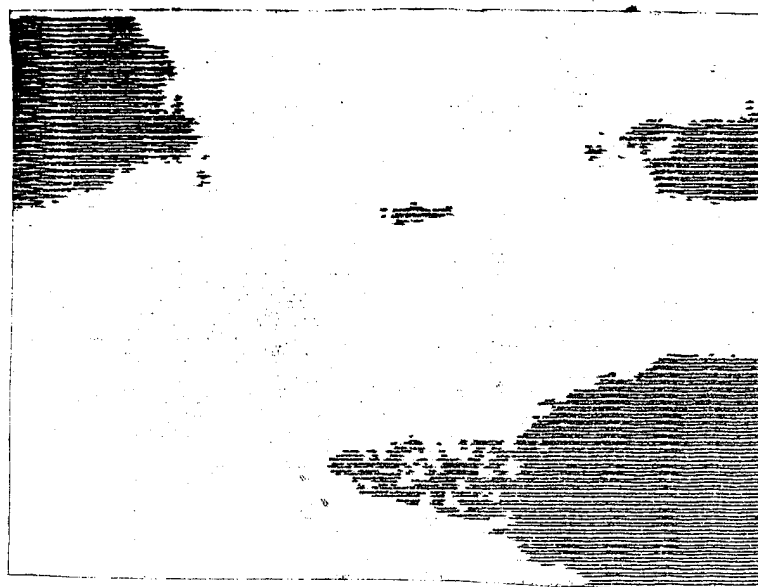


PRELOADED

10^3 CYCLES

1/8 FULL PENETRATION HOLE

SPECIMEN L2-1-28

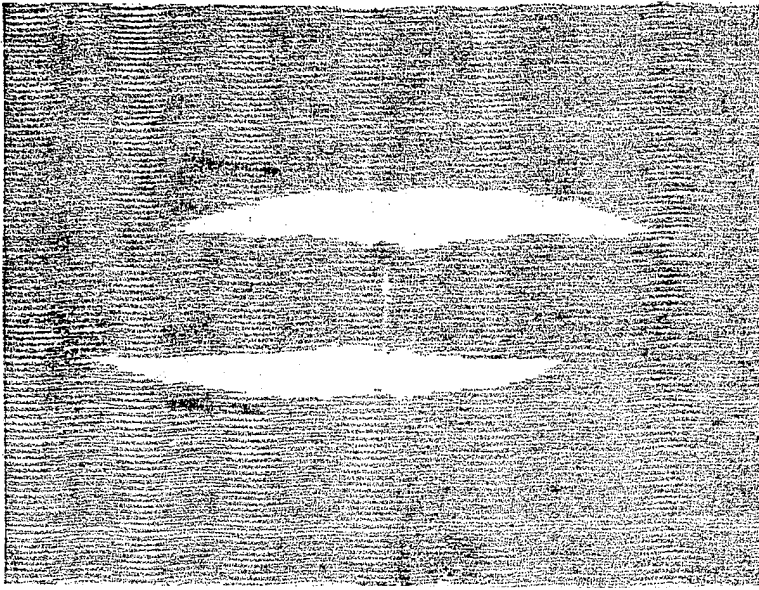


NO PRELOAD

1.5×10^6 CYCLES

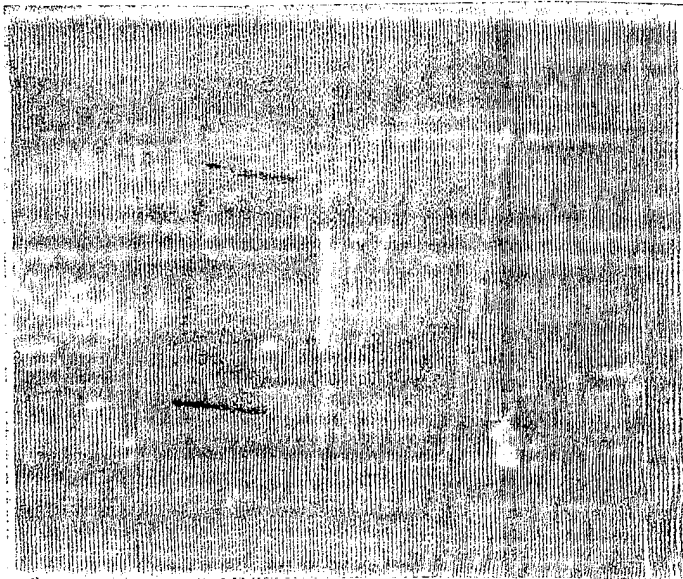
1/8 FULL PENETRATION HOLE

SPECIMEN L2-1-29



AFTER CYCLIC TEST
10³ CYCLES

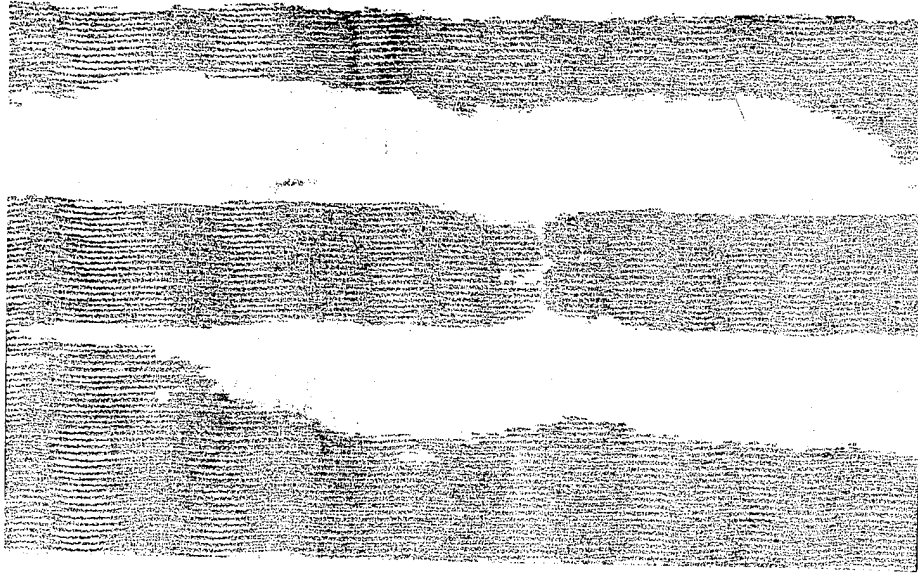
NO PRELOAD



BEFORE TEST
SPECIMEN NUMBER L2-1-42
5/8 FP SLIT

NOT INSPECTED

NOT INSPECTED



BEFORE TEST

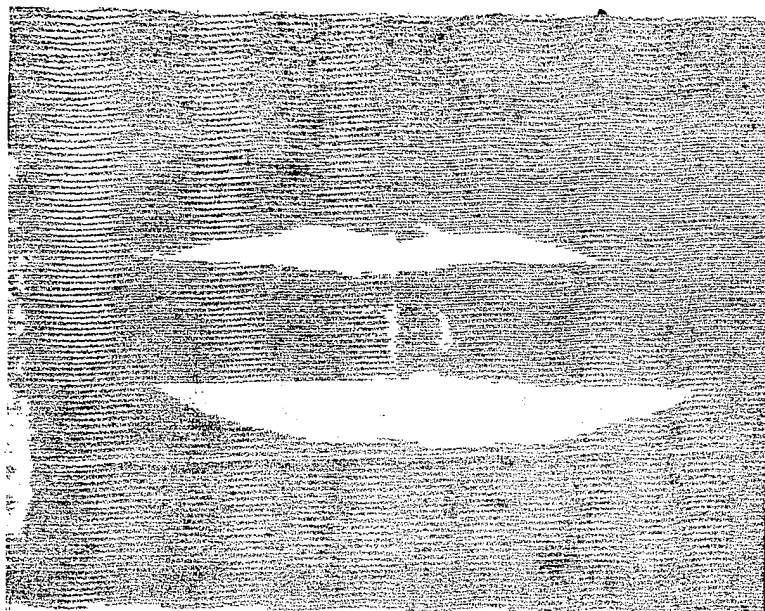
SPECIMEN NUMBER L2-1-43

5/8 FP SLIT

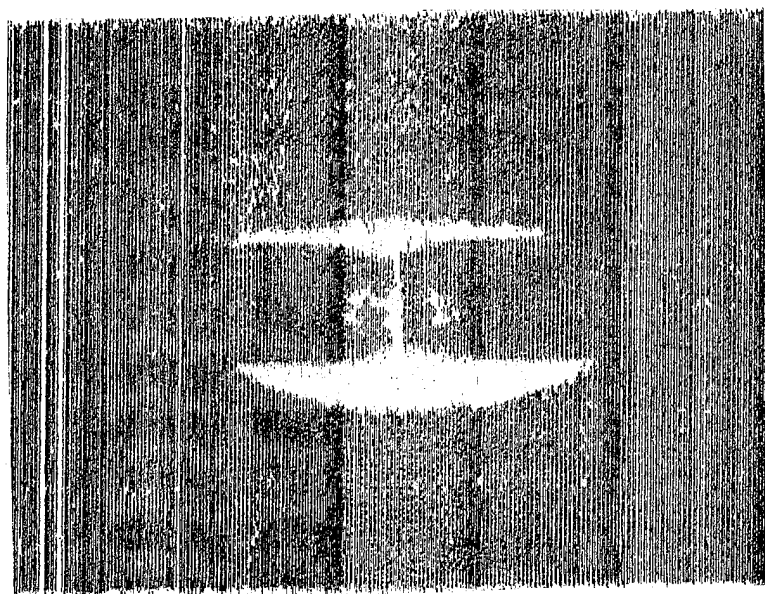
AFTER PRELOAD

AFTER CYCLIC TEST

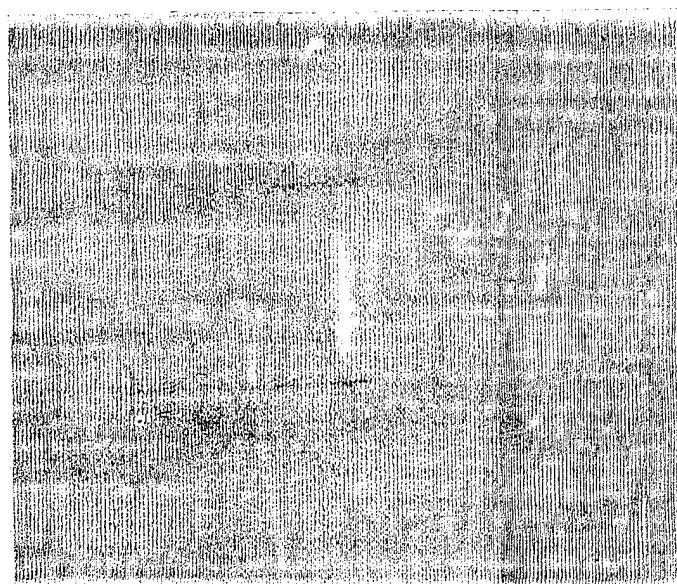
1.5 x 10⁶ CYCLES



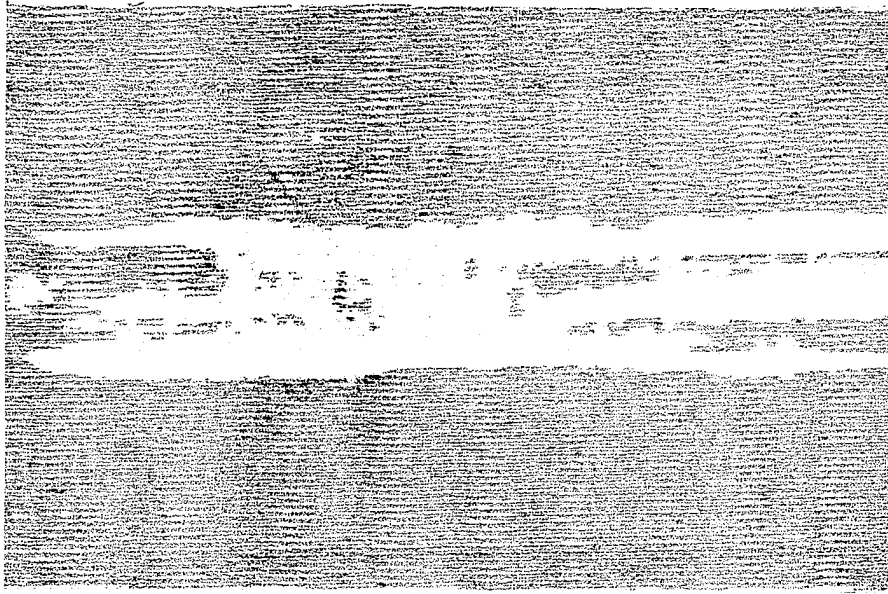
AFTER CYCLIC TEST
10³ CYCLES



AFTER PRELOAD



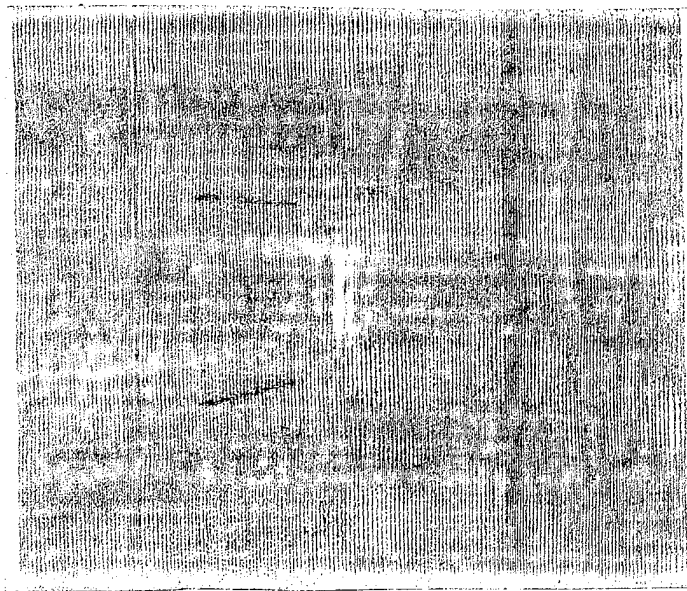
BEFORE TEST
SPECIMEN NUMBER L2-144
5/8 FP SLIT



AFTER CYCLIC TEST

10^3 CYCLES

NO PRELOAD

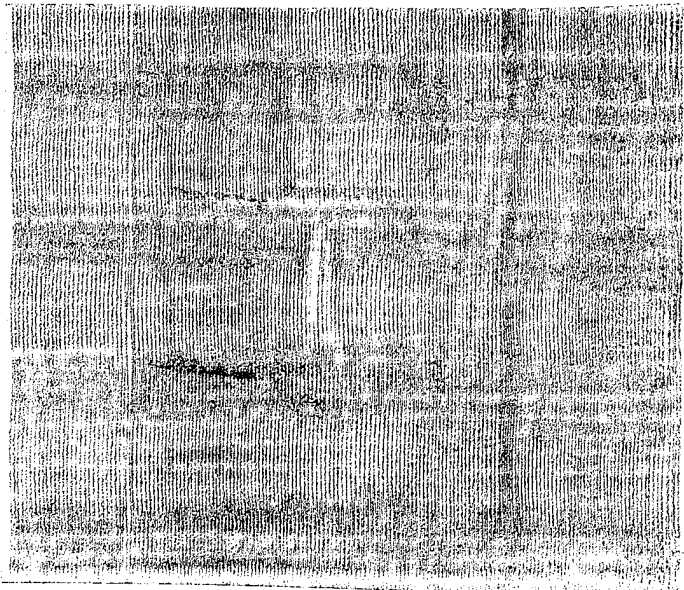
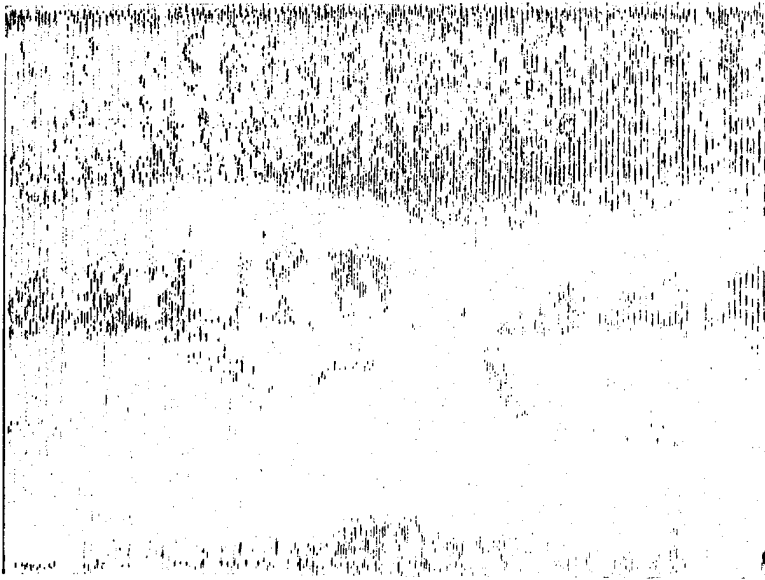


BEFORE TEST

SPECIMEN NUMBER L2-1-46

5/8 HP SLIT

FAILURE DURING
CYCLIC TEST

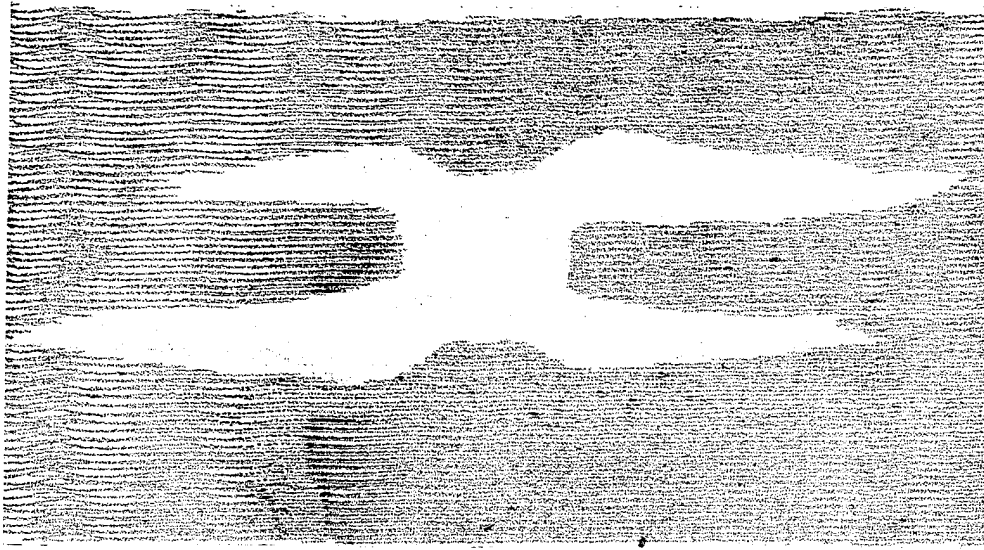


BEFORE TEST

AFTER PRELOAD

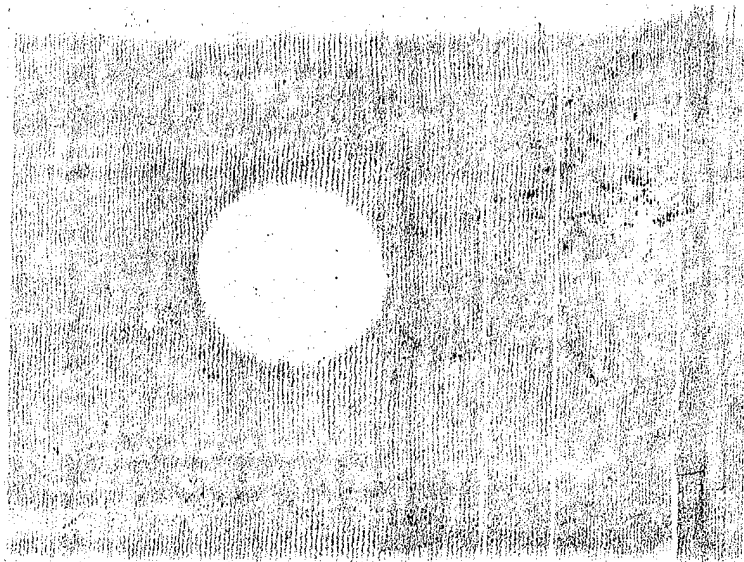
SPECIMEN NUMBER L2-1-48

5/8 HP SLIT

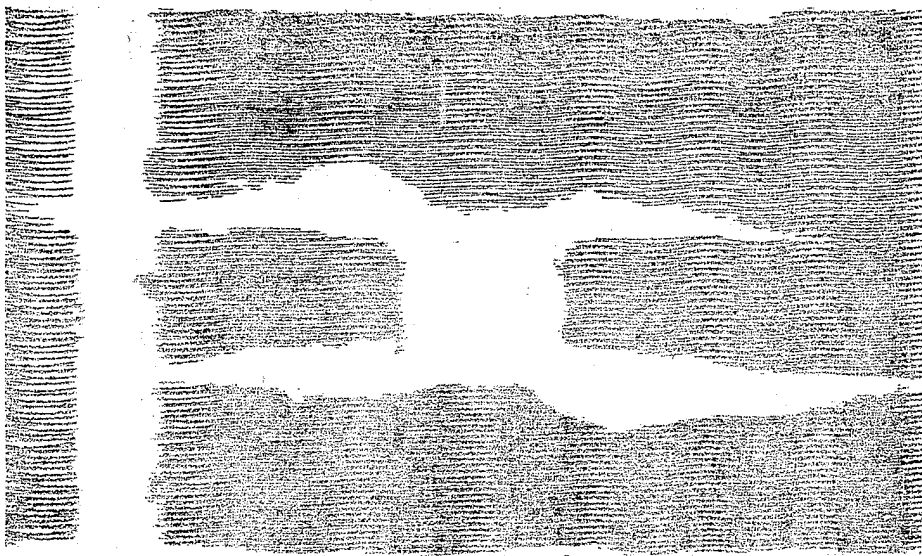


AFTER CYCLIC TEST
1.5 x 10⁶ CYCLES

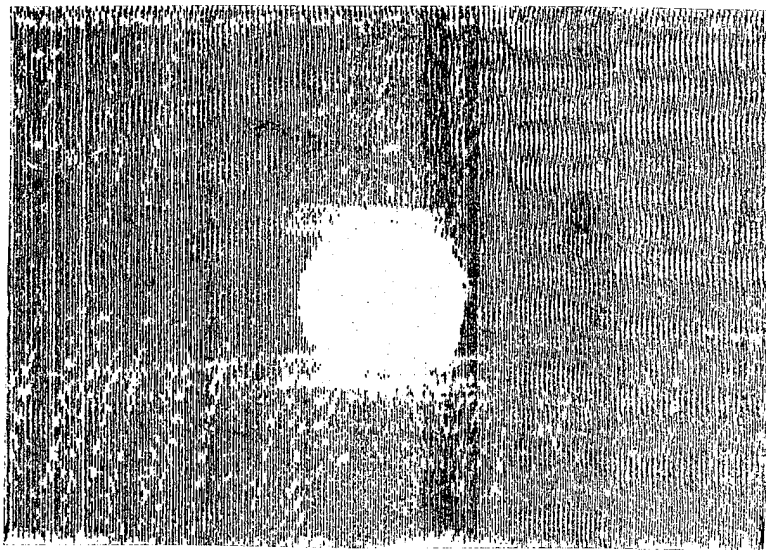
NO PRELOAD



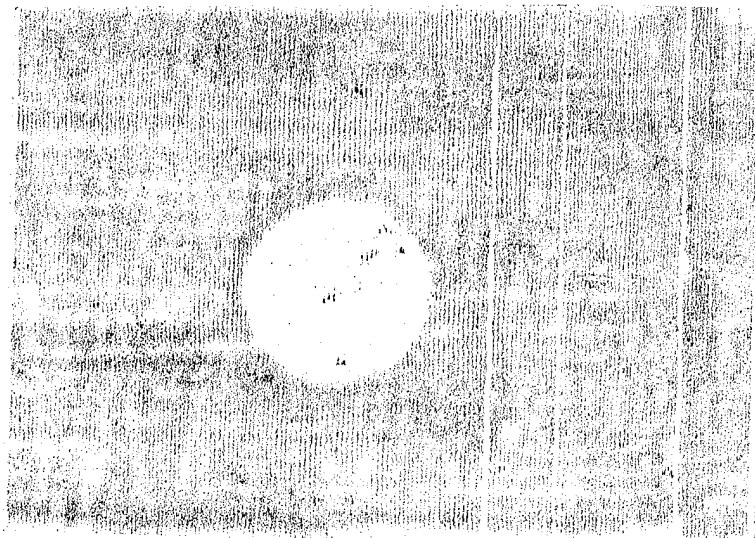
BEFORE TEST
SPECIMEN NUMBER L2-4-4
5/8 CSK HOLE



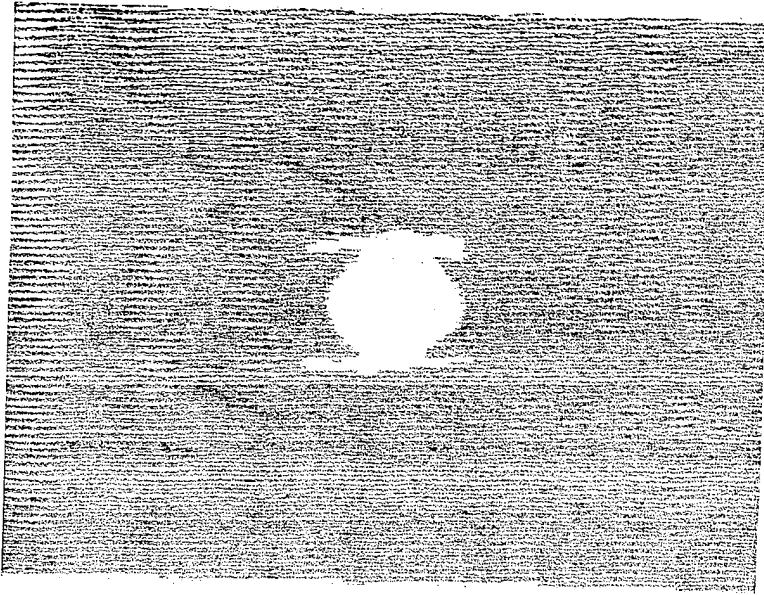
AFTER CYCLIC TEST
1.5 x 10⁶ CYCLES



AFTER PRELOAD

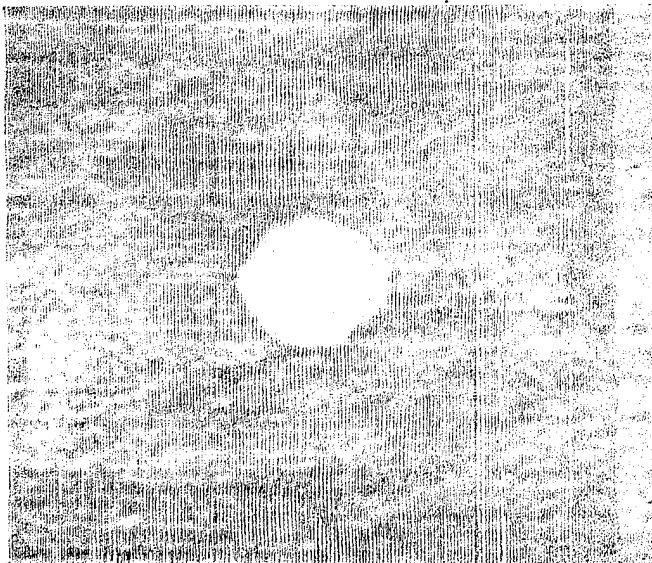


BEFORE TEST
SPECIMEN NUMBER L2-4-6
5/8 CSK HOLE

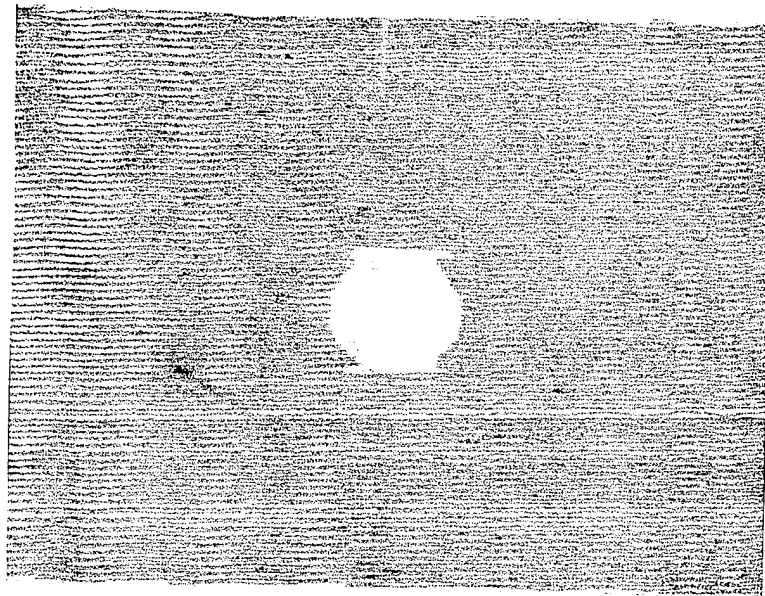


AFTER CYCLIC TEST
1.5 x 10⁶ CYCLES

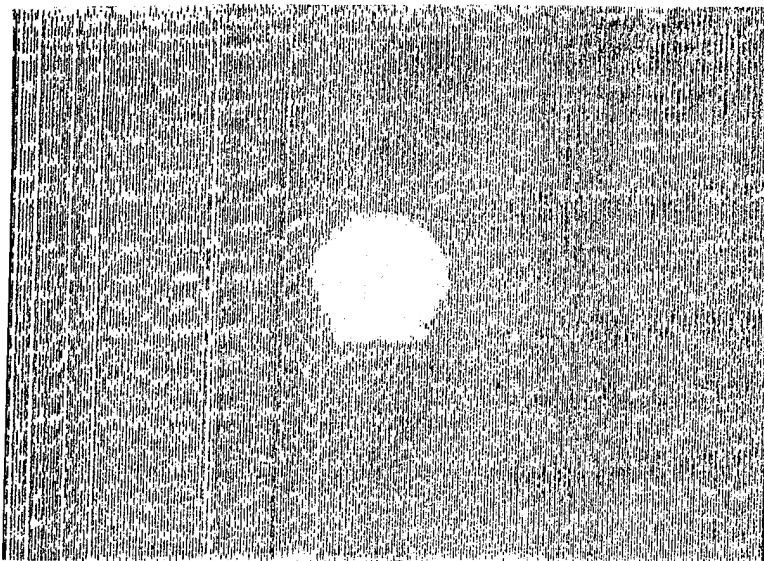
NO PRELOAD



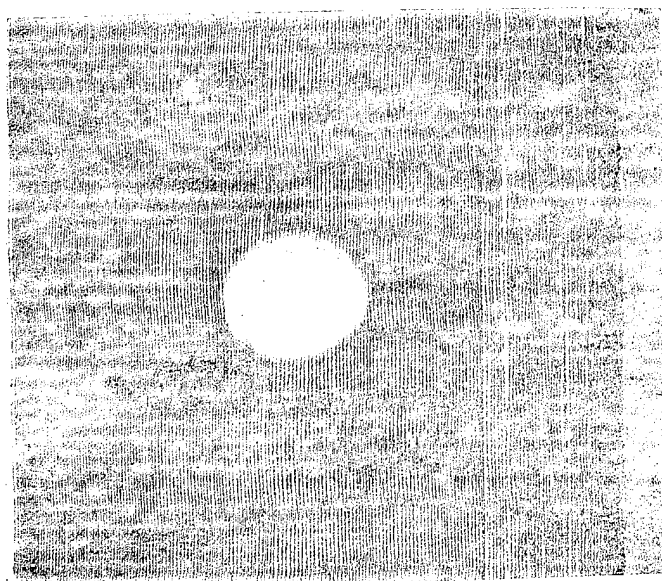
BEFORE TEST
SPECIMEN NUMBER L3-1-3
5/8 FP HOLE



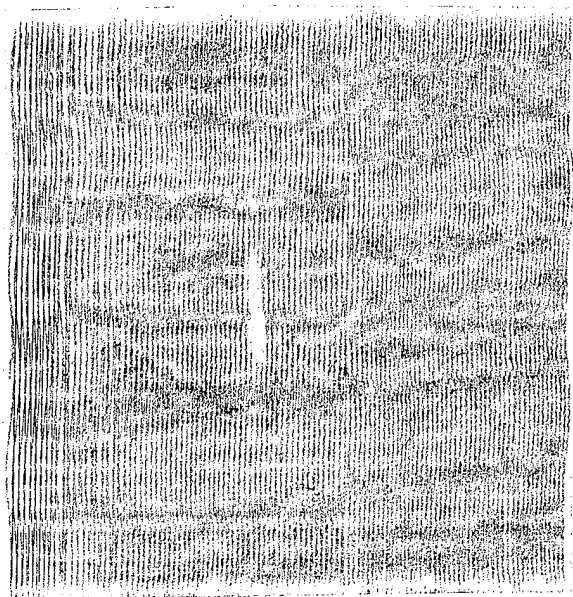
AFTER CYCLIC TEST
10³ CYCLES



AFTER PRELOAD

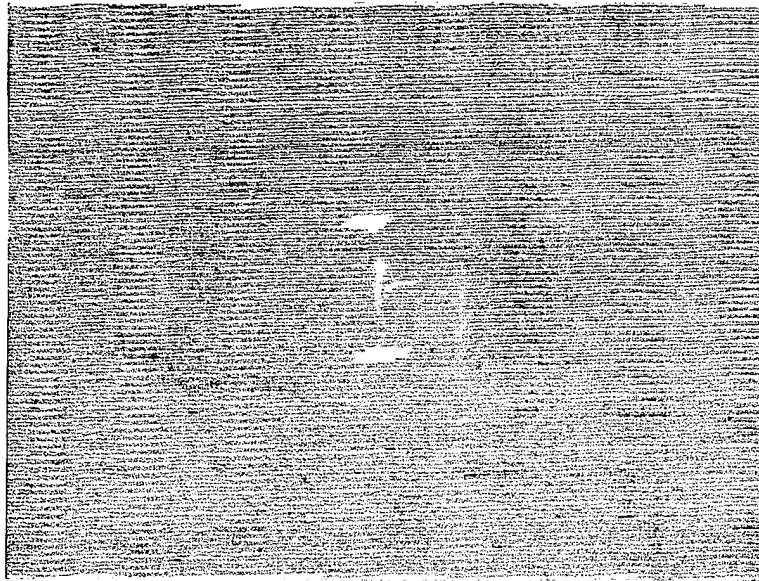


BEFORE TEST
SPECIMEN NUMBER L3-1-38
5/8 FP HOLE



BEFORE TEST
SPECIMEN NUMBER L3-1-56
5/8 FP SLIT

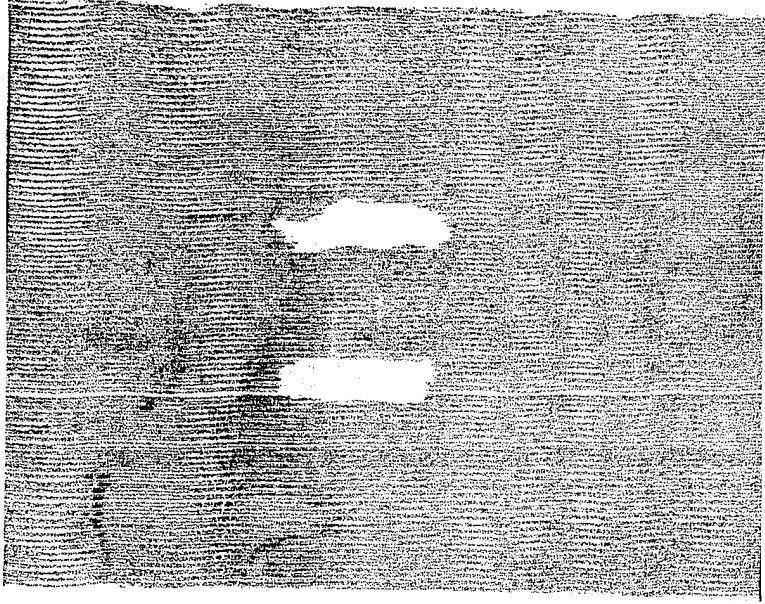
NO PRELOAD



AFTER CYCLIC TEST
 10^3 CYCLES

NOT INSPECTED

NO PRELOAD



BEFORE TEST

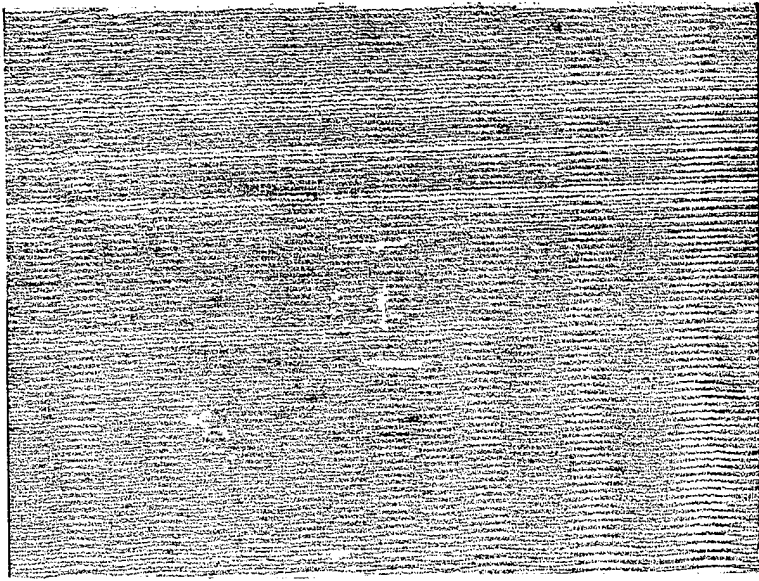
SPECIMEN NUMBER L3-1-55

5/8 FP SLIT

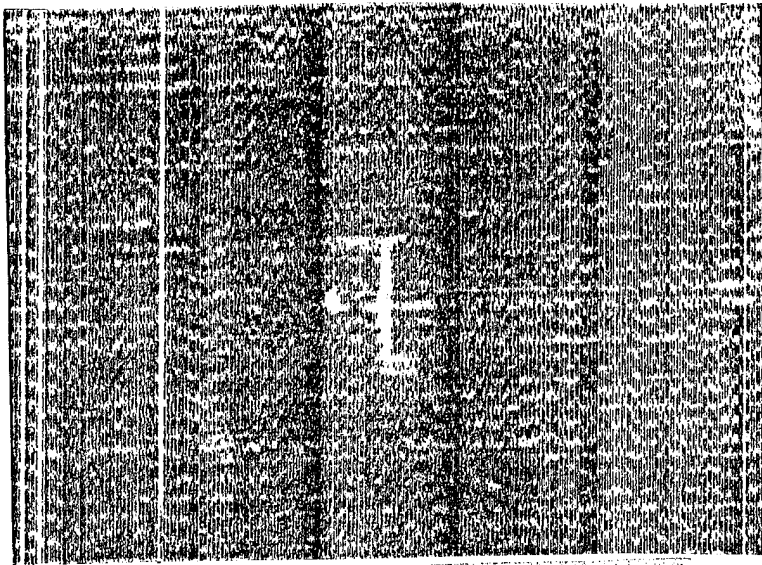
AFTER CYCLIC TEST

1.5 x 10⁶ CYCLES

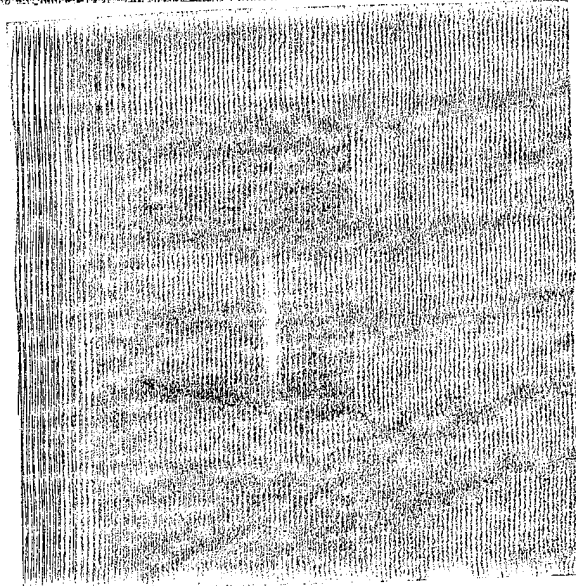




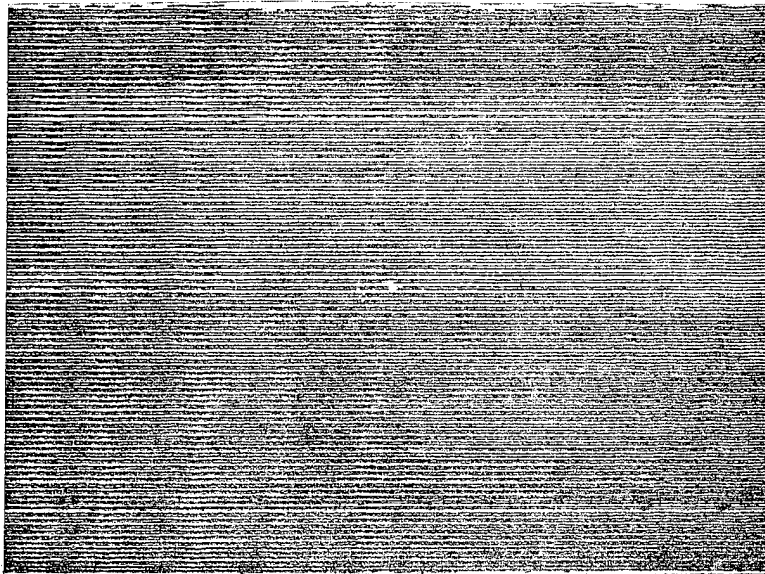
AFTER CYCLIC TEST
10³ CYCLES



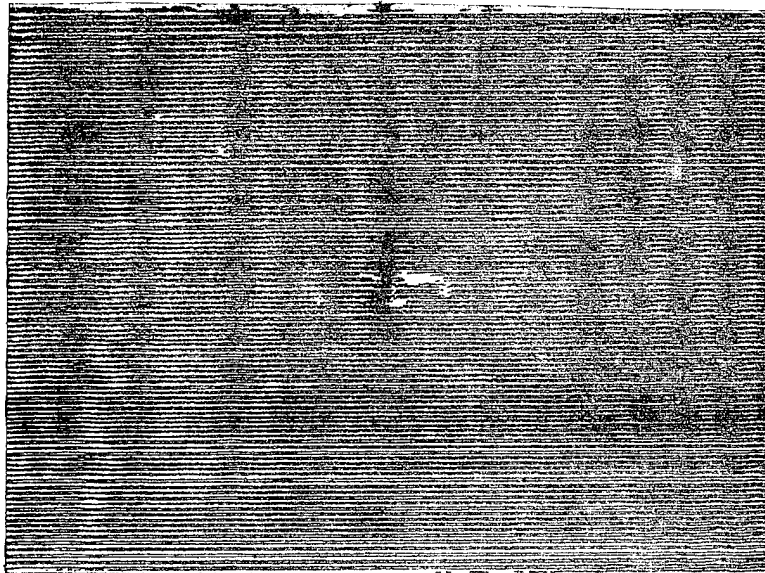
AFTER PRELOAD



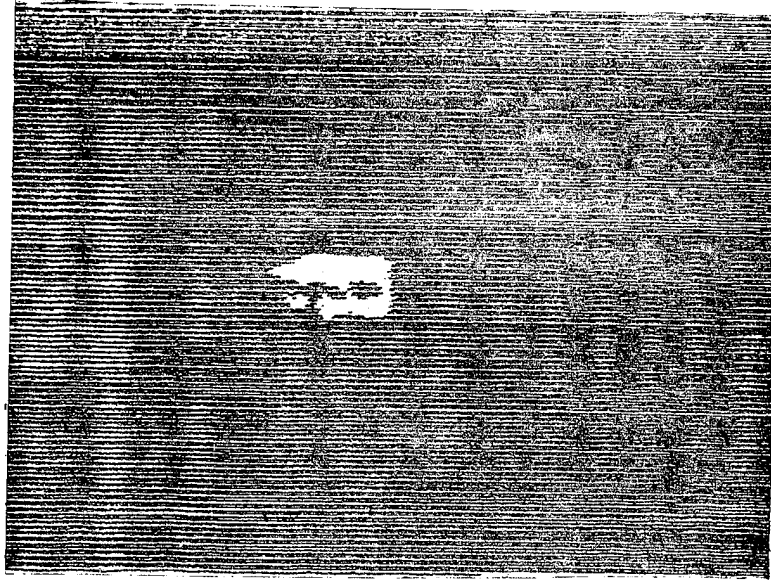
BEFORE TEST
SPECIMEN NUMBER L3-1-58
5/8 FP SLIT



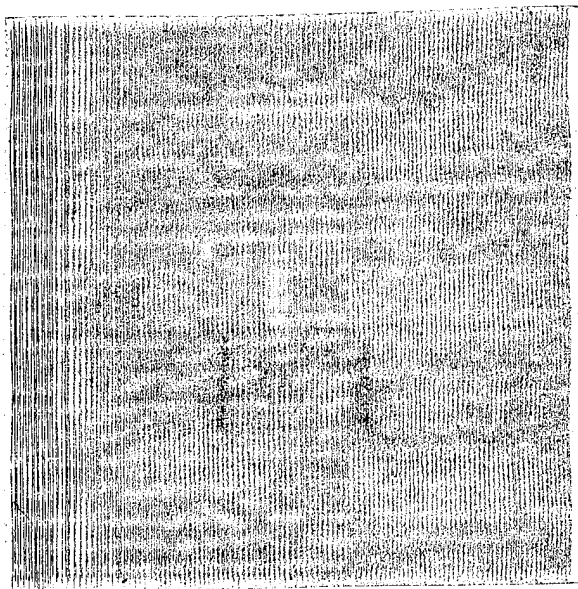
NO PRELOAD
 10^3 CYCLES
SPECIMEN NUMBER L3-1-40
1/8 FULL PENETRATION SLIT



PRELOADED
 10^3 CYCLES
SPECIMEN NUMBER L3-1-42
1/8 FULL PENETRATION SLIT



PRELOADED
 1.5×10^6 CYCLES
SPECIMEN NUMBER L3-1-41
1/8 FULL PENETRATION SLIT

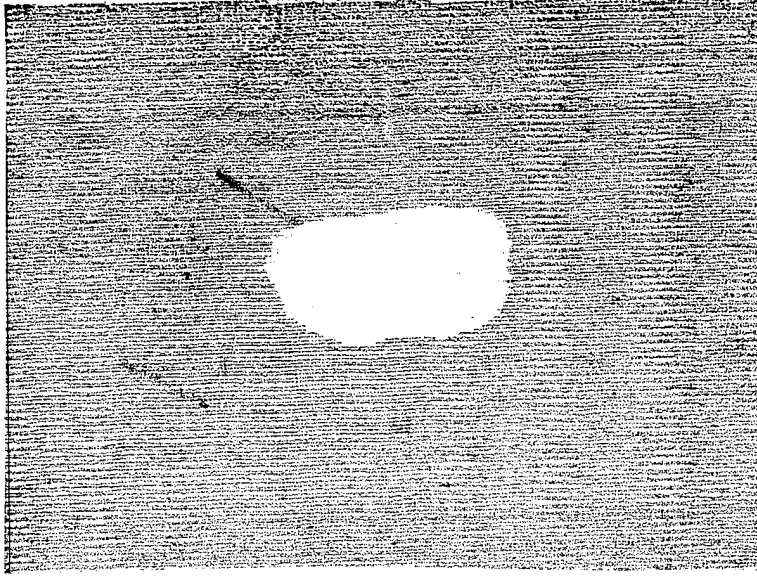


BEFORE TEST

SPECIMEN NUMBER L3-1-60

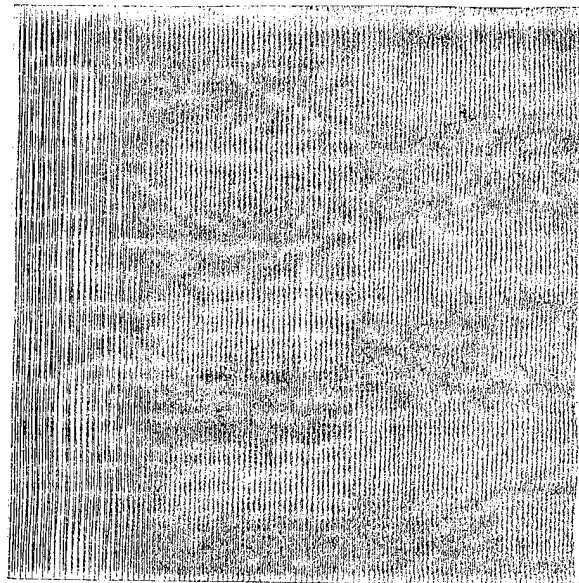
5/8 HP SLIT

NO PRELOAD



AFTER CYCLIC TEST

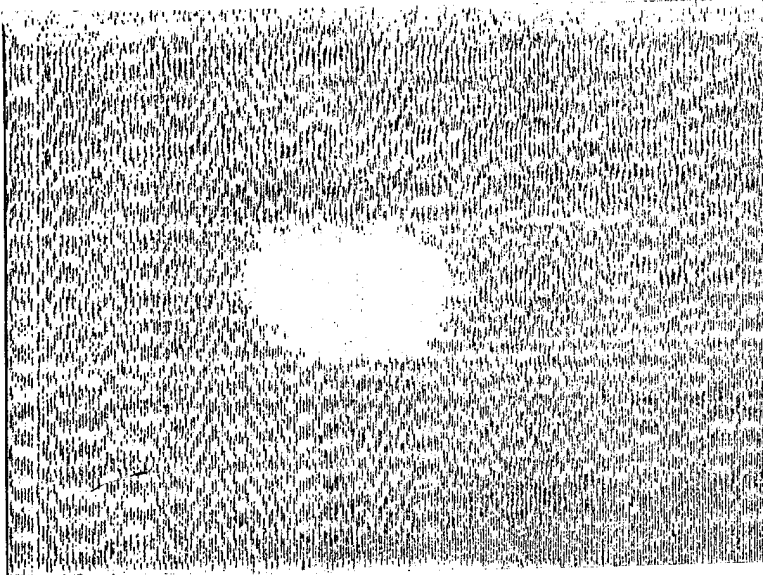
10^3 CYCLES



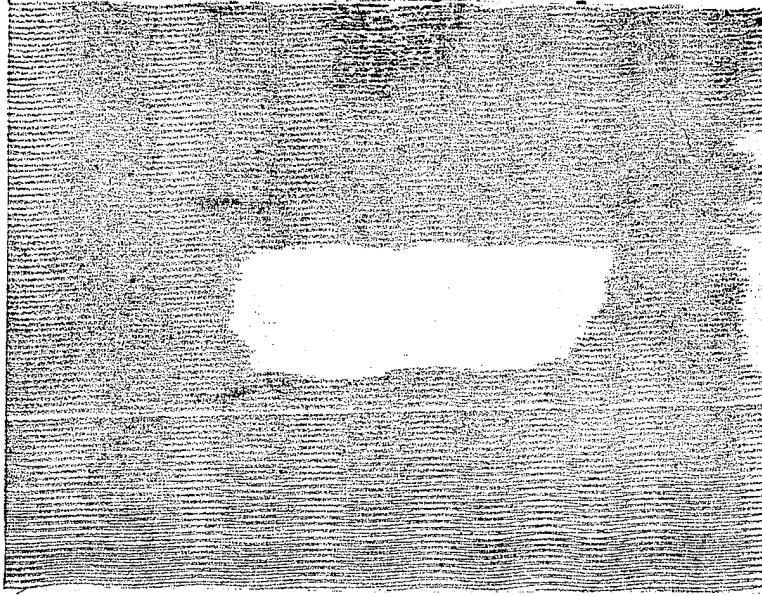
BEFORE TEST

SPECIMEN NUMBER L3-1-62

5/8 HP SLIT

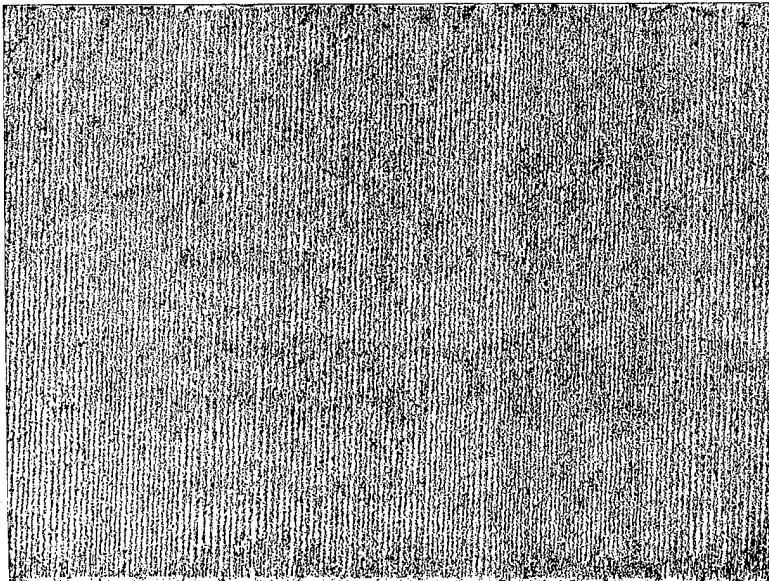


AFTER PRELOAD



AFTER CYCLIC TEST

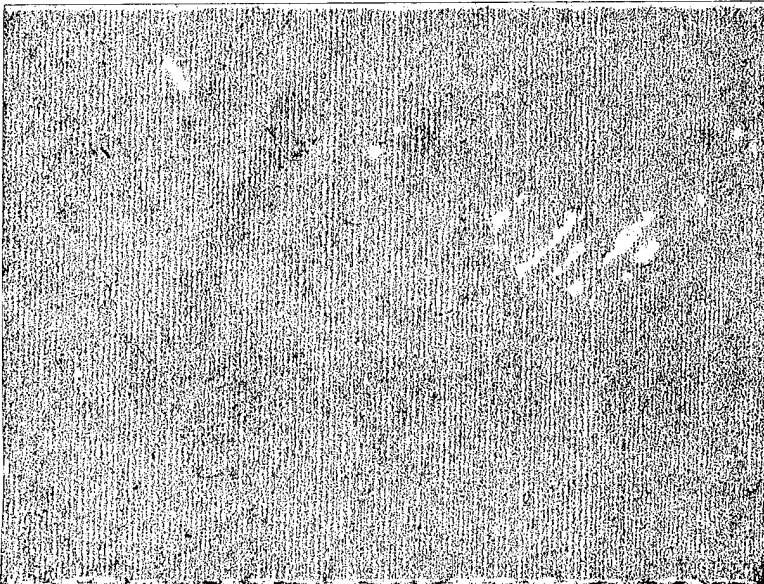
10^3 CYCLES



BEFORE TEST

SPECIMEN NUMBER L1-10-1

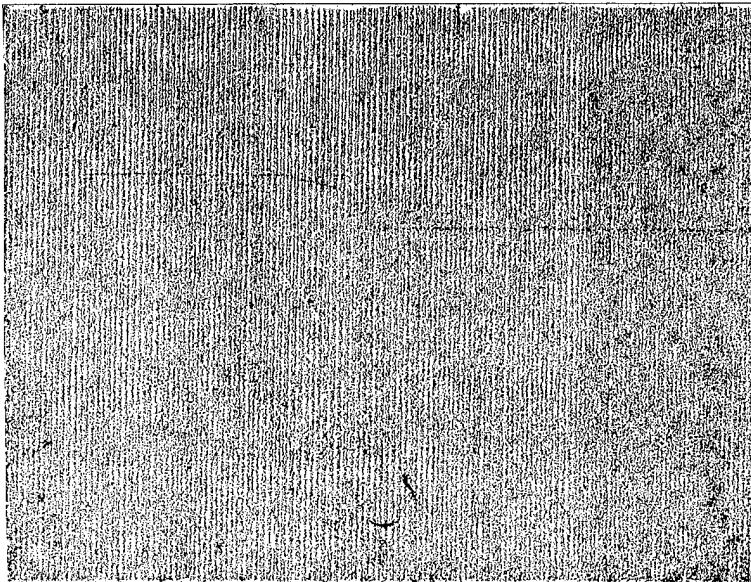
NO DEFECT



BEFORE TEST
SPECIMEN NUMBER L1-10-2
NO DEFECT



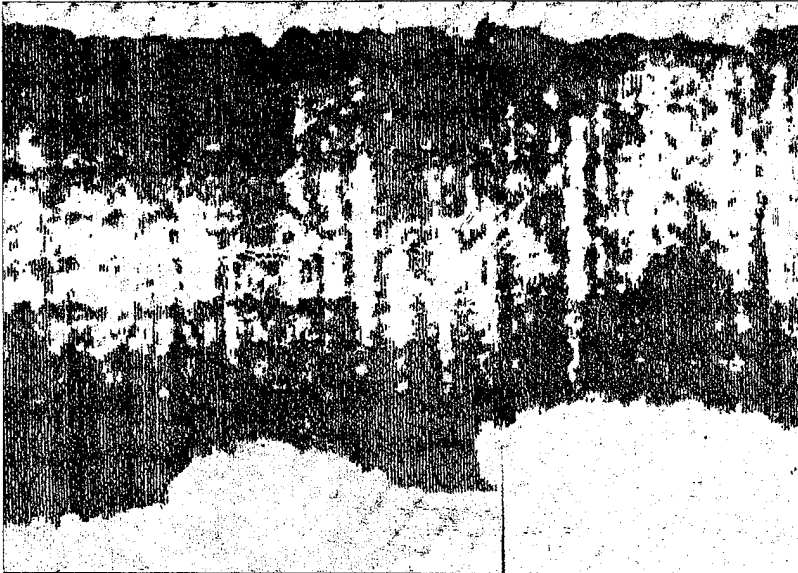
AFTER CYCLIC TEST
10³ CYCLES



BEFORE TEST

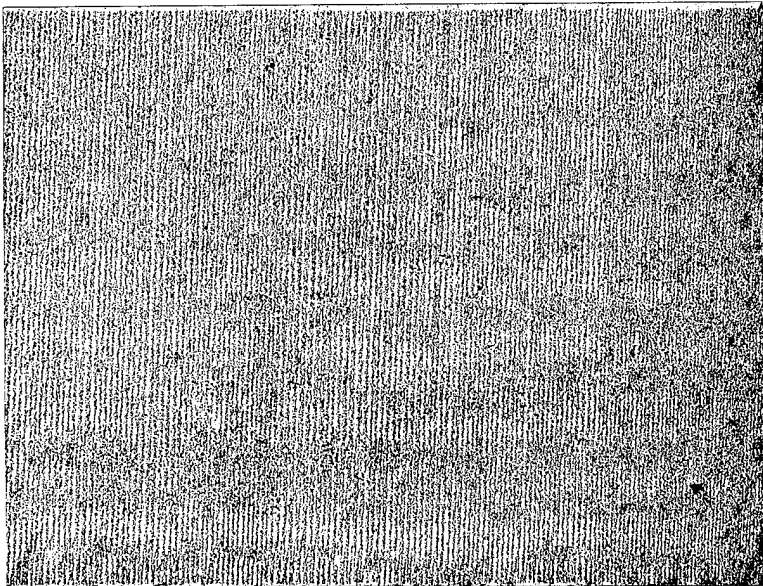
SPECIMEN NUMBER L1-10-3

NO DEFECT



AFTER CYCLIC TEST

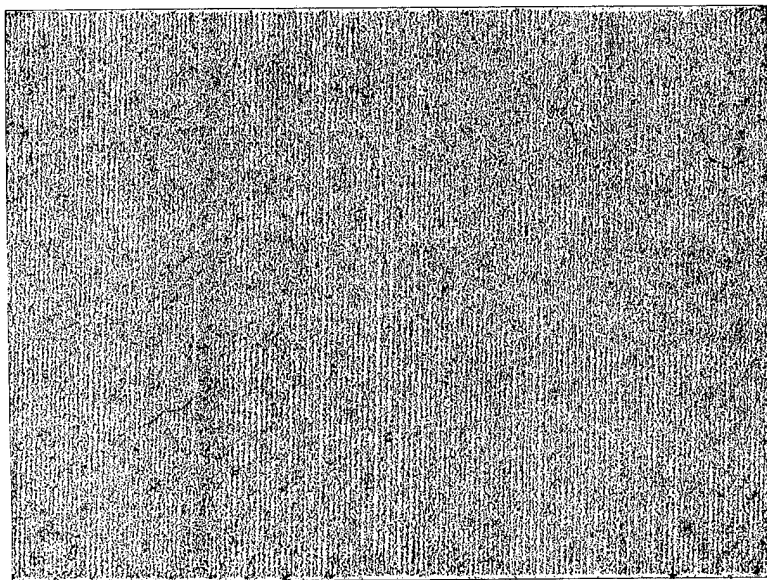
337 700 CYCLES



BEFORE TEST

SPECIMEN NUMBER L1-10-4

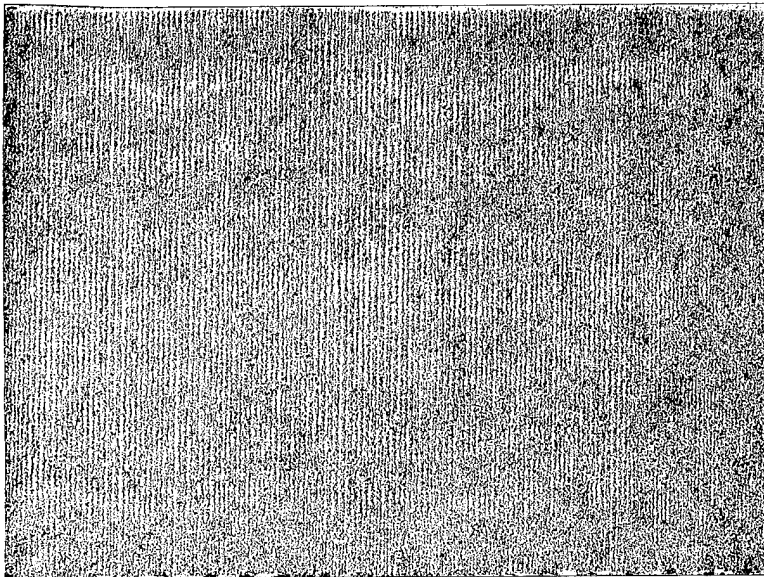
NO DEFECT



BEFORE TEST

SPECIMEN NUMBER L1-10-5

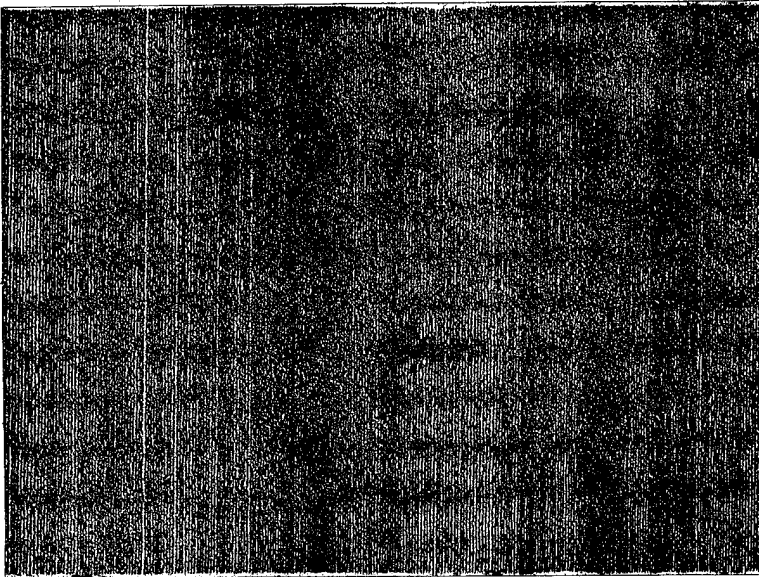
NO DEFECT



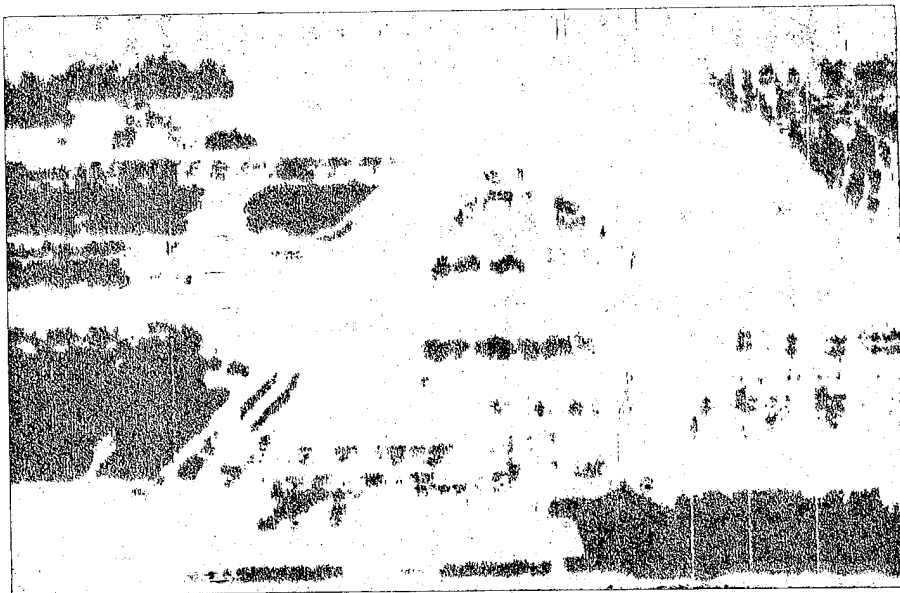
BEFORE TEST

SPECIMEN L1-10-6

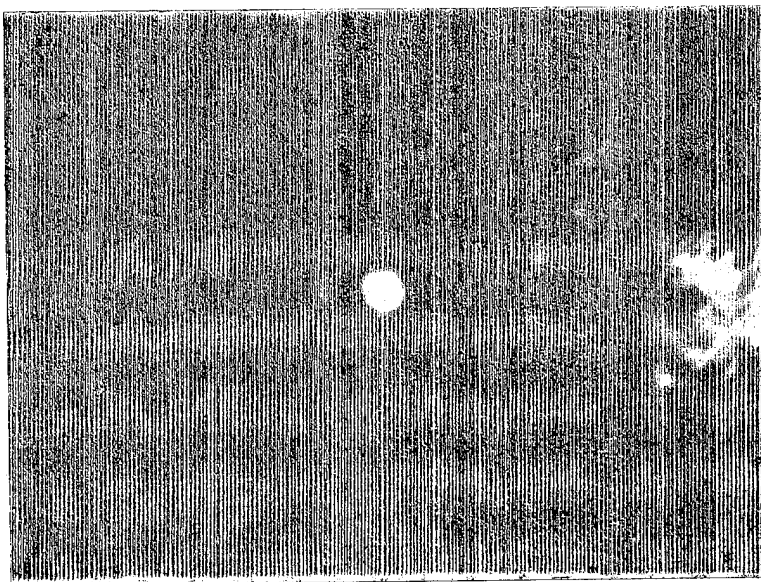
NO DEFECT



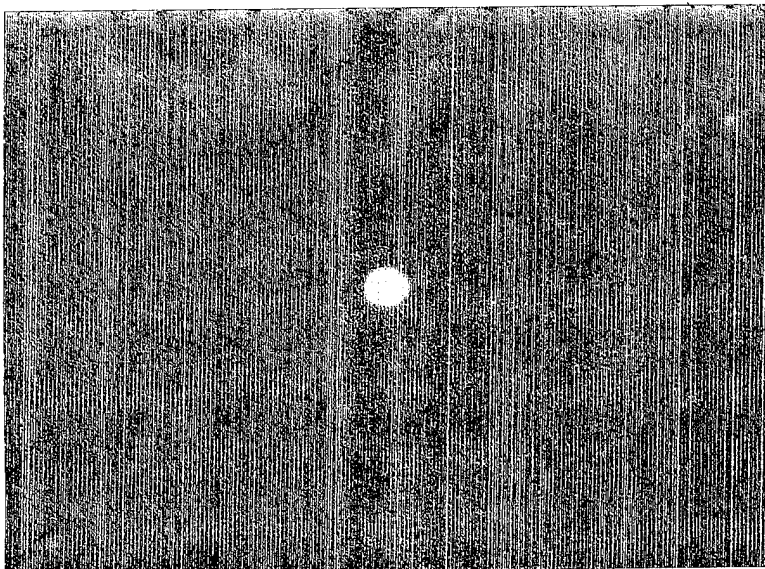
AFTER PRELOAD



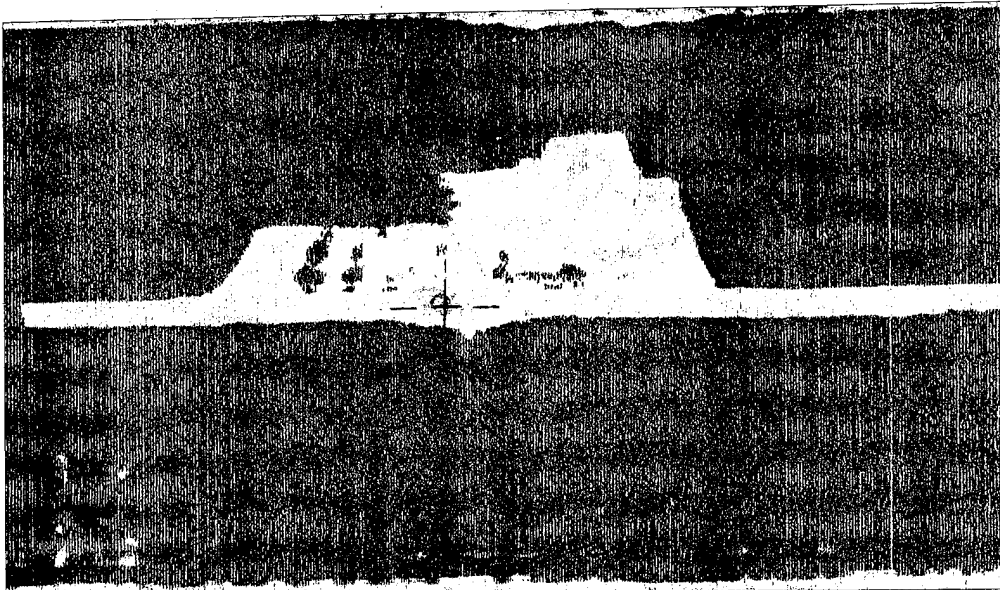
AFTER CYCLIC TEST
83,900 CYCLES



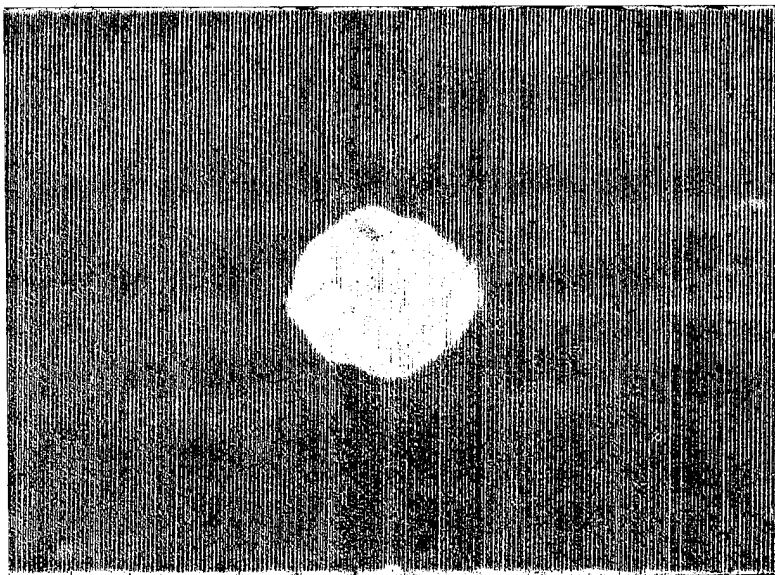
BEFORE TEST
SPECIMEN NUMBER L1-10-7
1/8 FULL PENETRATION HOLE



BEFORE TEST
SPECIMEN NUMBER L1-10-8
1/8 FULL PENETRATION HOLE

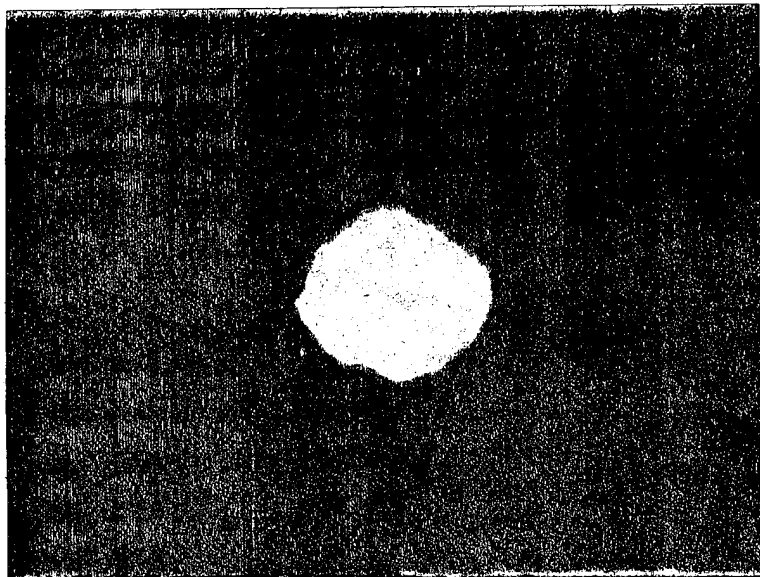


AFTER CYCLIC TEST
566 600 CYCLES



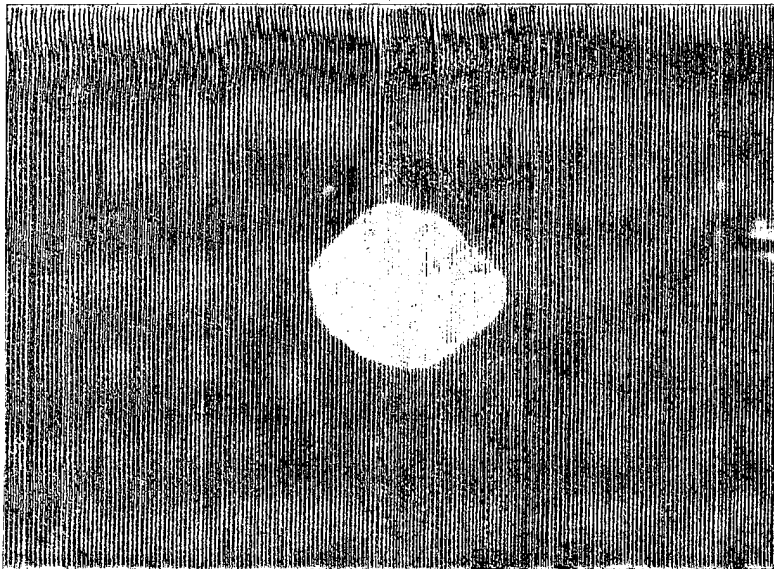
BEFORE TEST

SPECIMEN NUMBER L1-10-9
5/8 FULL PENETRATION HOLE



AFTER CYCLIC TEST

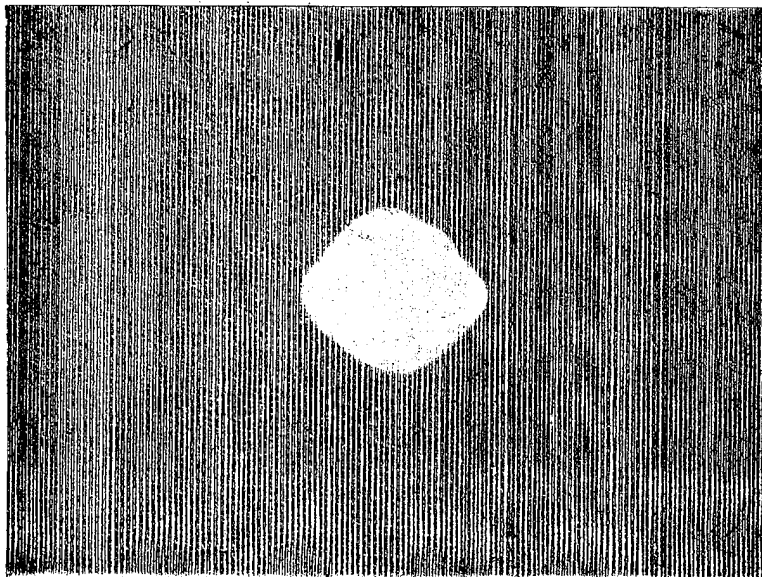
10^3 CYCLES



BEFORE TEST

SPECIMEN NUMBER L1-10-10

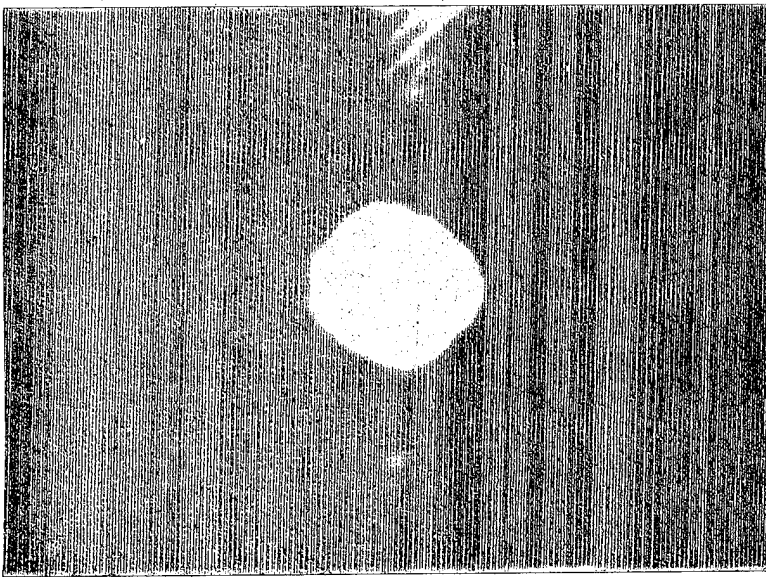
5/8 FULL PENETRATION HOLE



BEFORE TEST

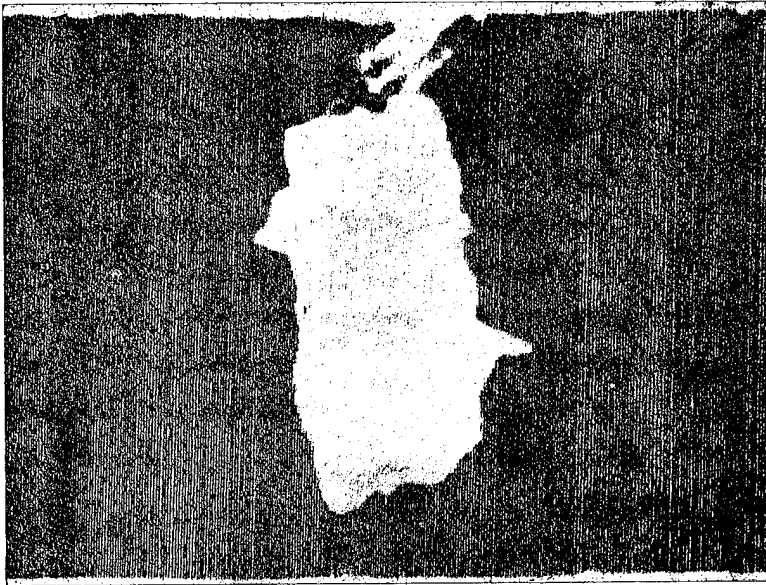
SPECIMEN NUMBER L1-10-11

5/8 FULL PENETRATION HOLE



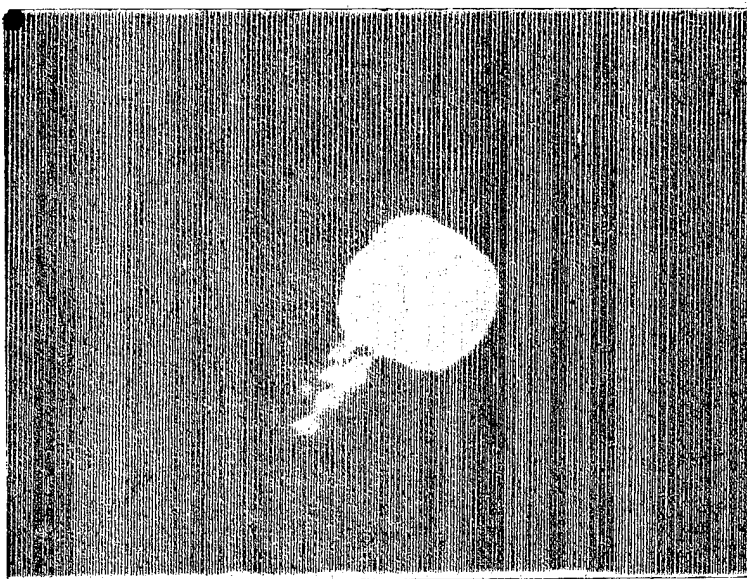
BEFORE TEST

SPECIMEN NUMBER L1-10-12
5/8 FULL PENETRATION HOLE



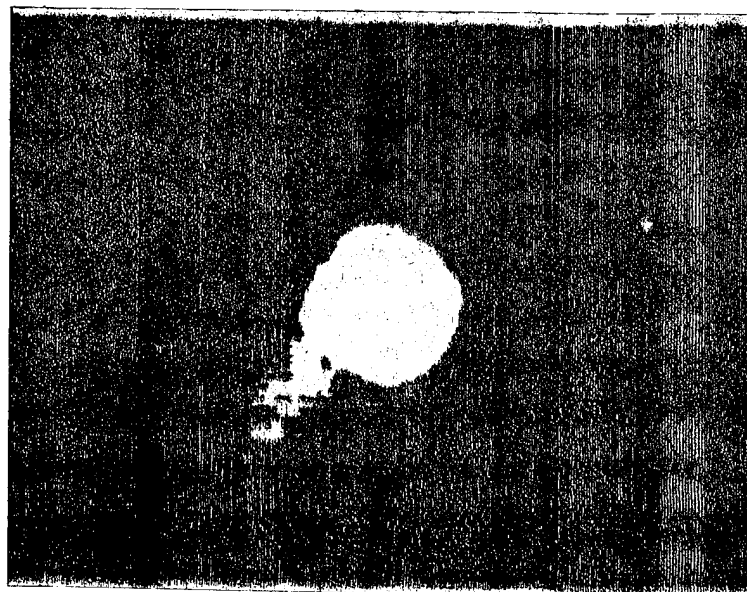
AFTER CYCLIC TEST

1.5 x 10⁶ CYCLES

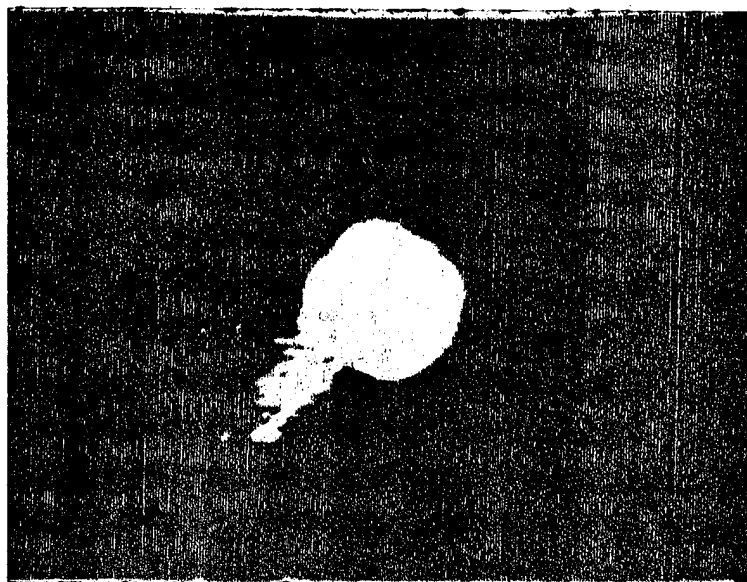


BEFORE TEST

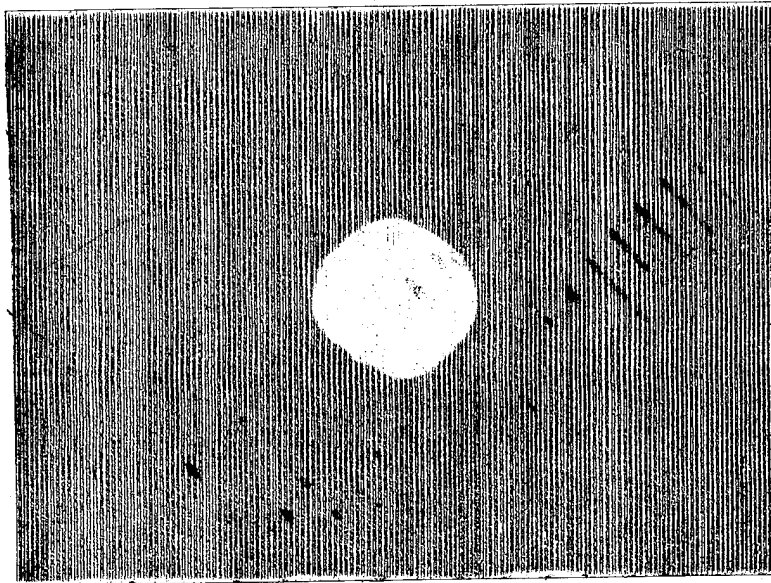
SPECIMEN NUMBER L1-10-13
5/8 FULL PENETRATION HOLE



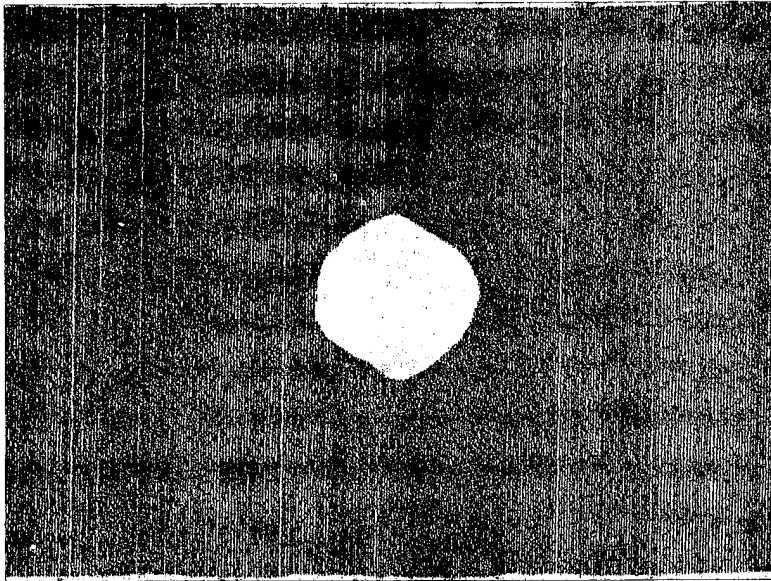
AFTER PRELOAD



AFTER CYCLIC TEST
 10^3 CYCLES



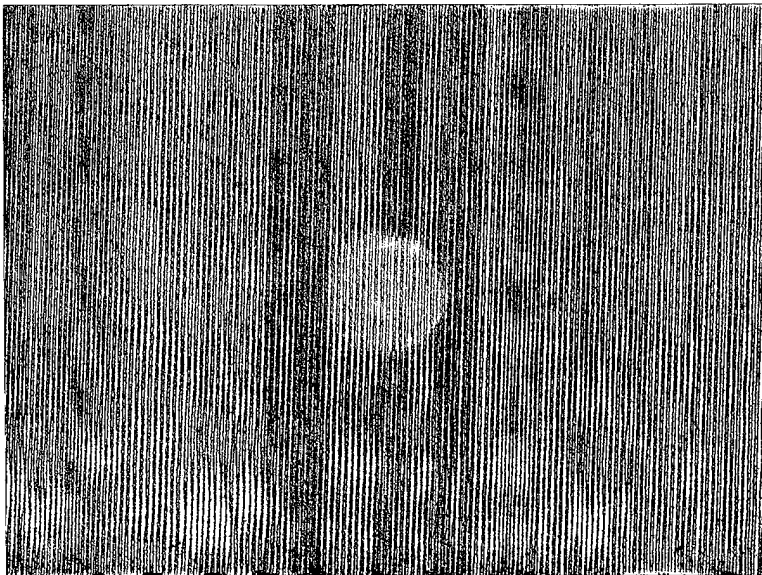
BEFORE TEST



AFTER PRELOAD

SPECIMEN NUMBER L1-10-14

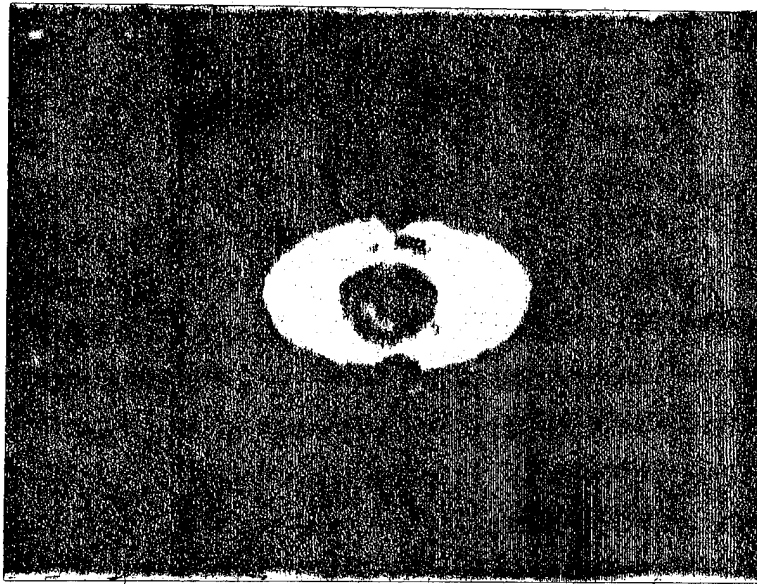
5/8 FULL PENETRATION HOLE



BEFORE TEST

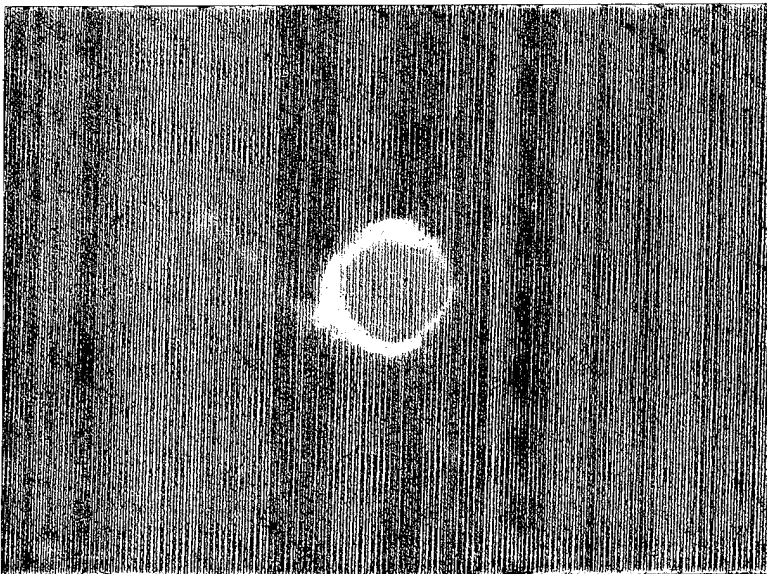
SPECIMEN NUMBER L1-10-15

5/8 HALF PENETRATION HOLE



AFTER CYCLIC TEST

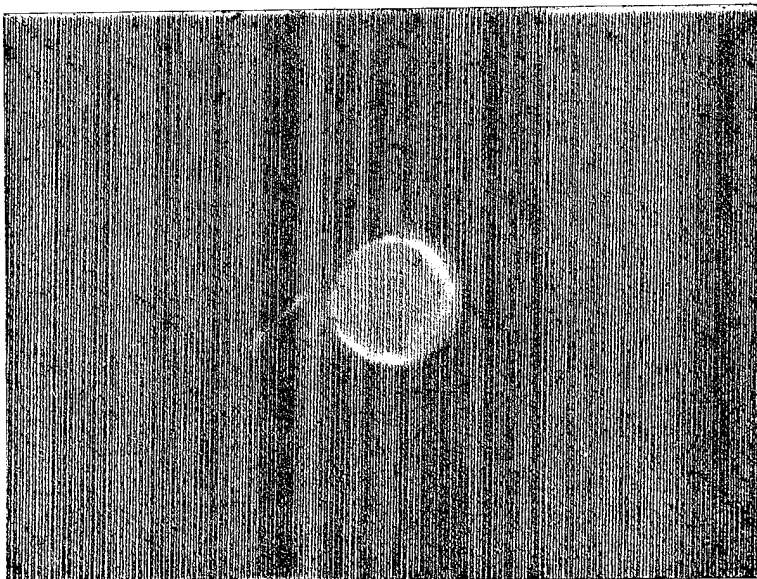
10³ CYCLES



BEFORE TEST

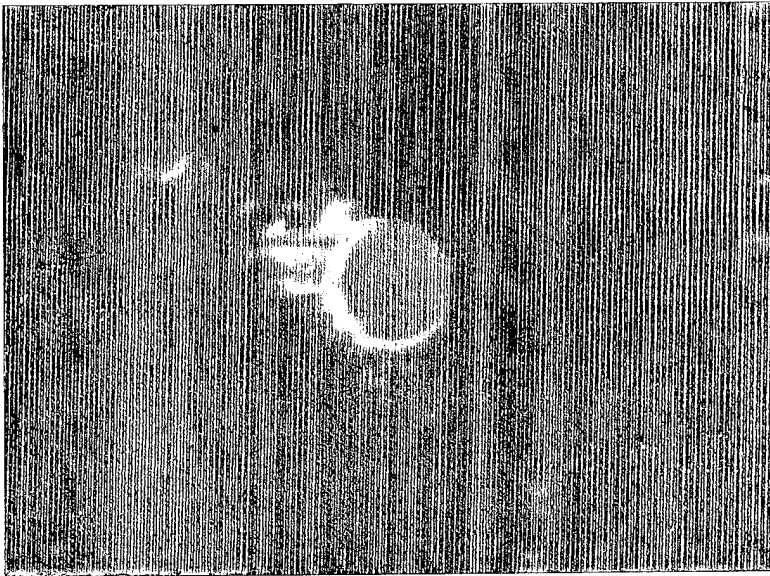
SPECIMEN NUMBER L1-10-16

5/8 HALF PENETRATION HOLE



BEFORE TEST

SPECIMEN NUMBER L1-10-17
5/8 HALF PENETRATION HOLE



BEFORE TEST

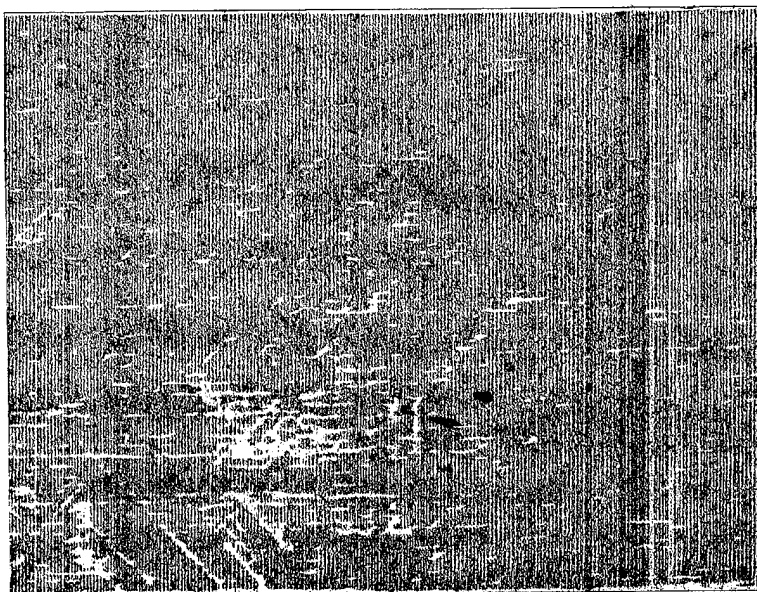
SPECIMEN NUMBER L1-10-18

5/8 HALF PENETRATION HOLE



AFTER CYCLIC TEST

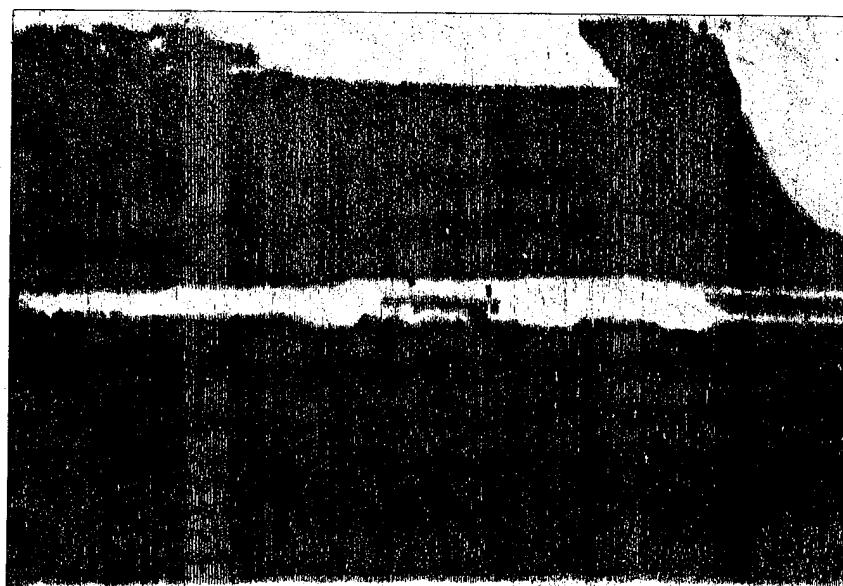
1.5×10^6 CYCLES



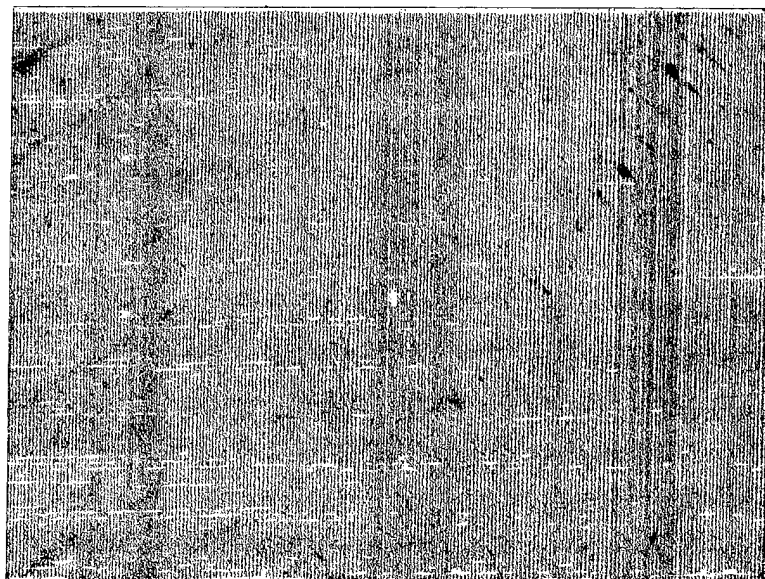
BEFORE TEST

SPECIMEN NUMBER L1-10-19

1/8 FULL PENETRATION SLIT



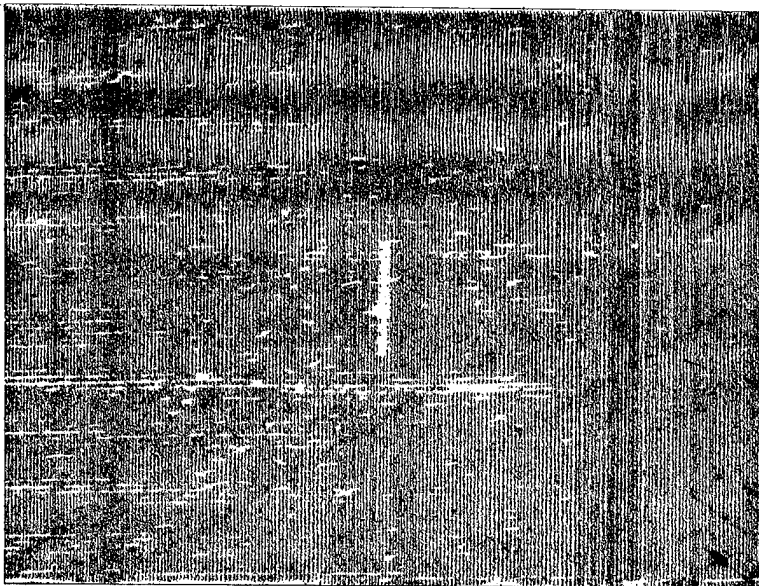
AFTER CYCLIC TEST



BEFORE TEST

SPECIMEN NUMBER L1-10-20

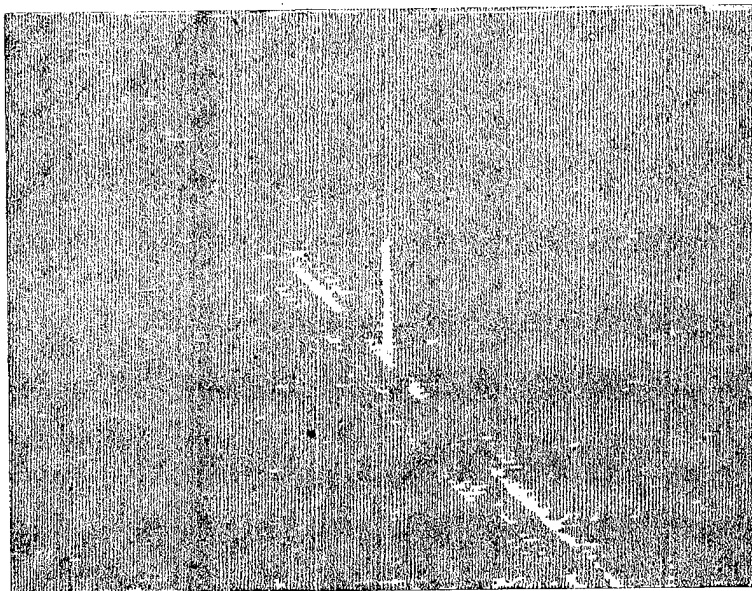
1/8 FULL PENETRATION SLIT



BEFORE TEST

SPECIMEN NUMBER L1-10-21

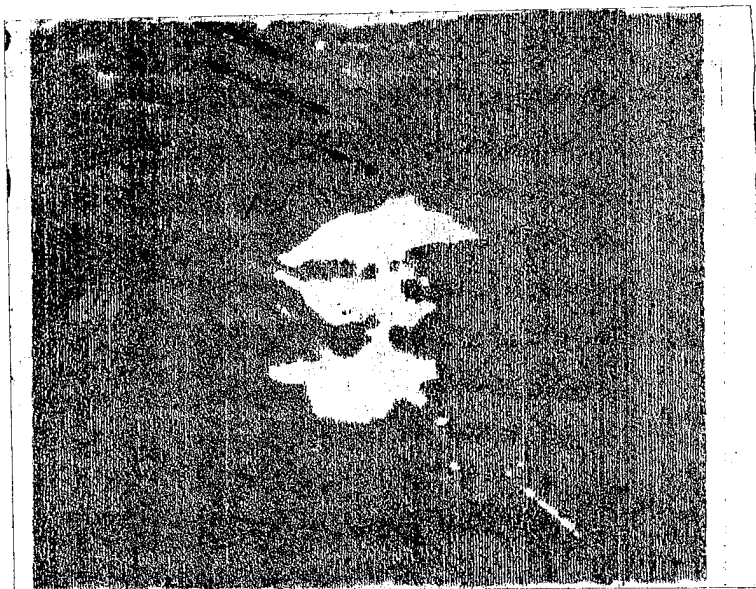
5/8 FULL PENETRATION SLIT



BEFORE TEST

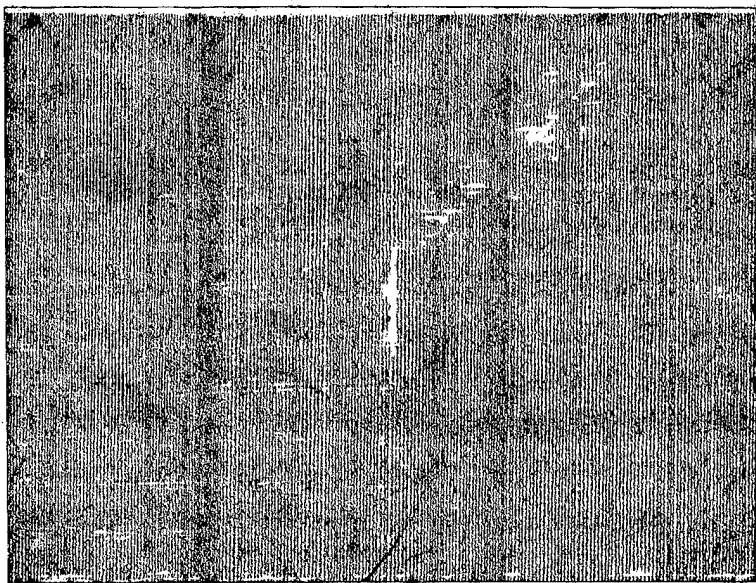
SPECIMEN NUMBER L1-10-22

5/8 FULL PENETRATION SLIT



AFTER CYCLIC TEST

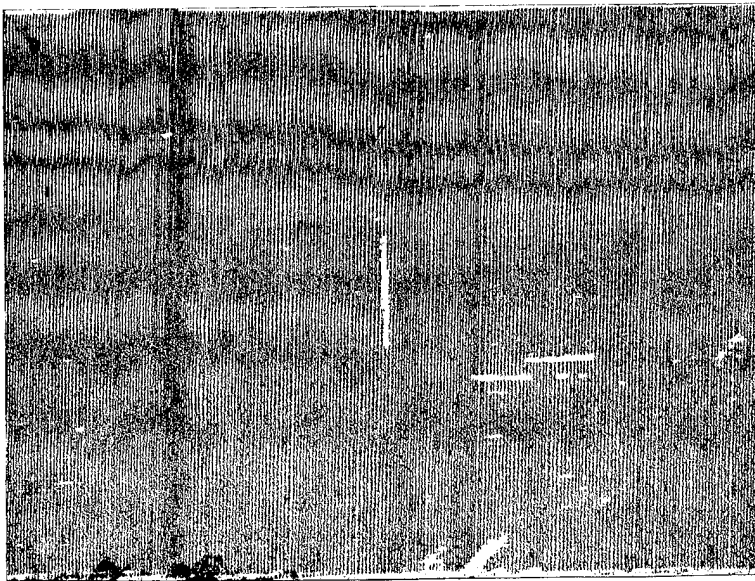
1.5 x 10⁶ CYCLES



BEFORE TEST

SPECIMEN NUMBER L1-10-23

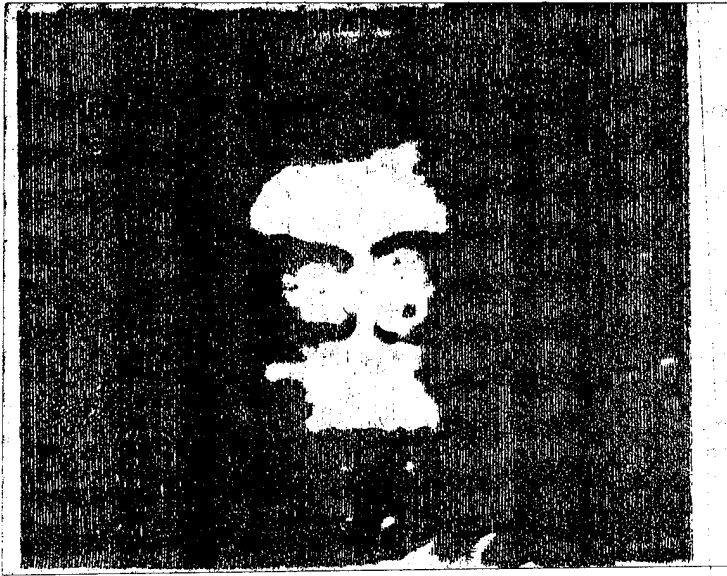
5/8 FULL PENETRATION SLIT



BEFORE TEST

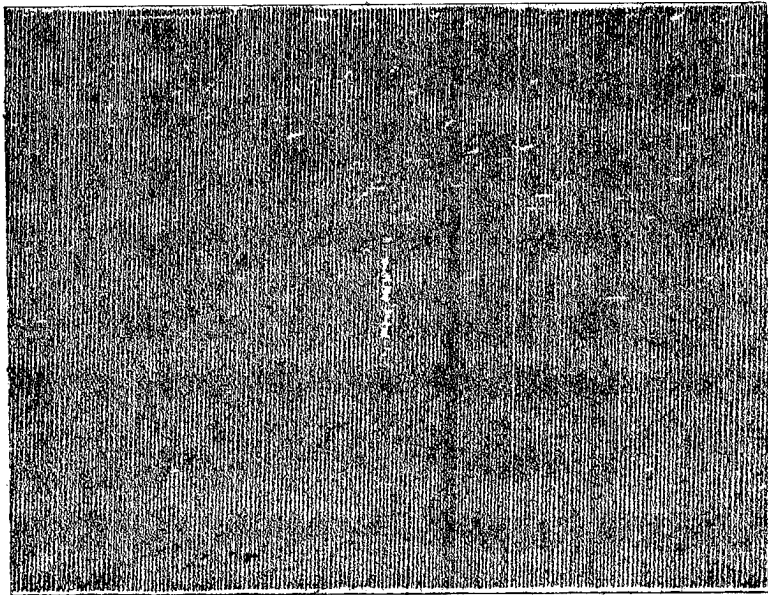
SPECIMEN NUMBER L1-10-24

5/8 FULL PENETRATION SLIT

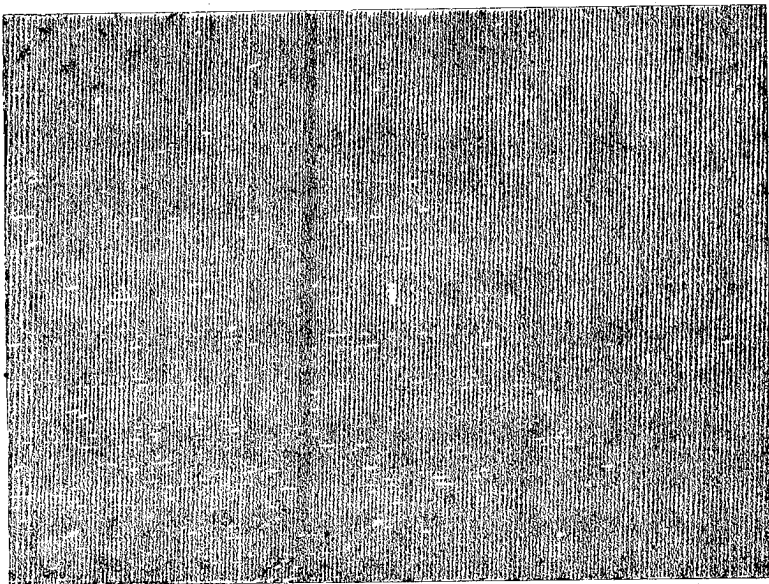


AFTER CYCLIC TEST

1.5×10^6 CYCLES



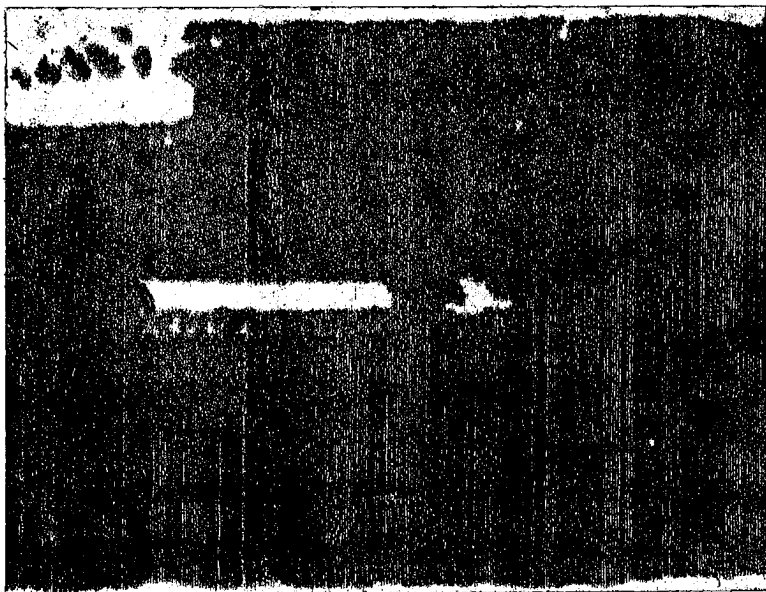
BEFORE TEST
SPECIMEN NUMBER L1-10-25
5/8 FULL PENETRATION SLIT



BEFORE TEST

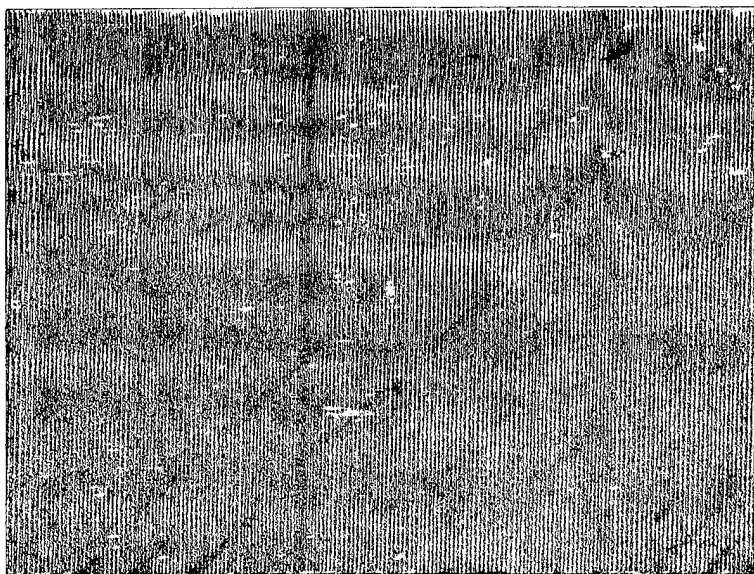
SPECIMEN NUMBER L1-10-26

1/8 HALF PENETRATION SLIT

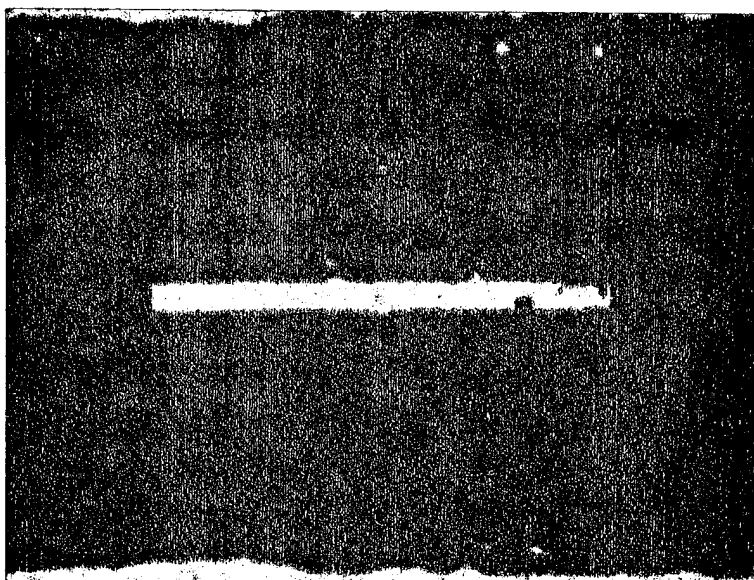


AFTER CYCLIC TEST

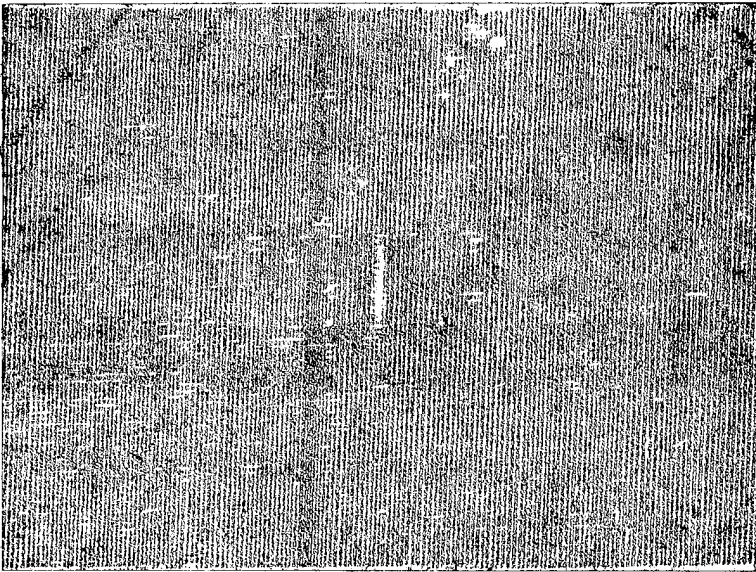
23 800 CYCLES



BEFORE TEST
SPECIMEN NUMBER L1-10-27
1/8 HALF PENETRATION SLIT



AFTER CYCLIC TEST
114 600 CYCLES



BEFORE TEST

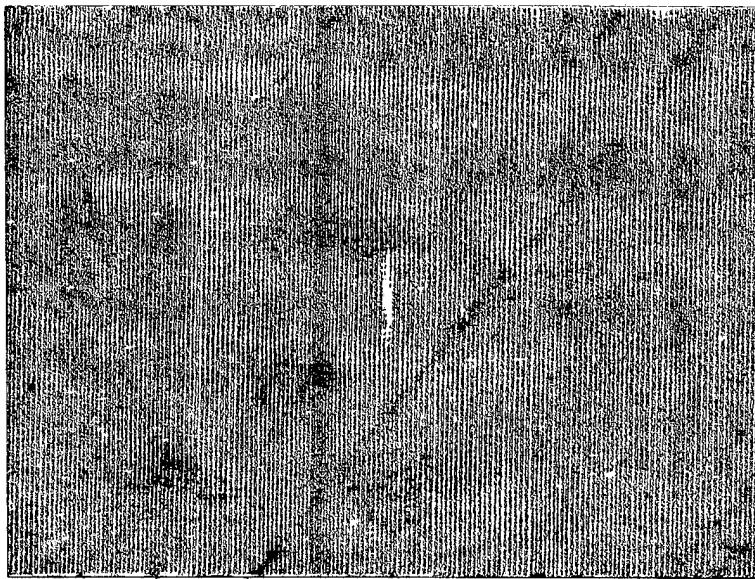
SPECIMEN NUMBER L1-10-28

5/8 HALF PENETRATION SLIT

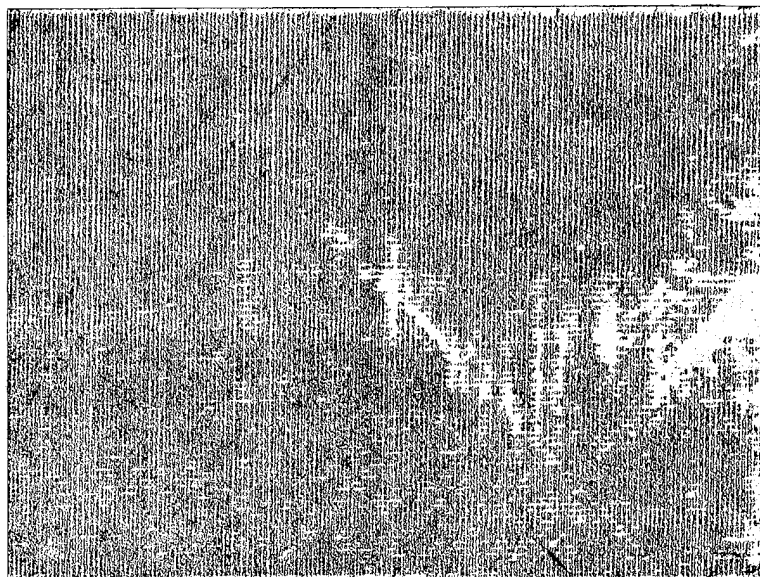


AFTER CYCLIC TEST

10^3 CYCLES



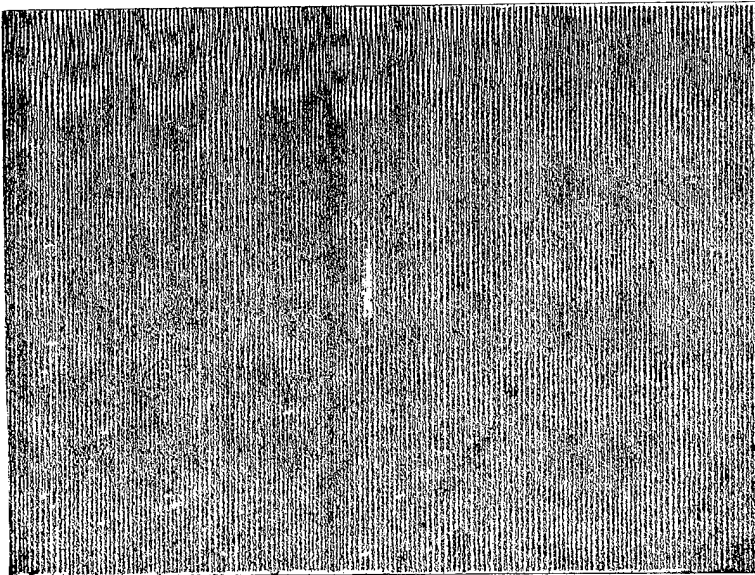
BEFORE TEST
SPECIMEN NUMBER L1-10-29
5/8 HALF PENETRATION SLIT



BEFORE TEST

SPECIMEN L1-10-30

5/8 HALF PENETRATION SLIT



BEFORE TEST

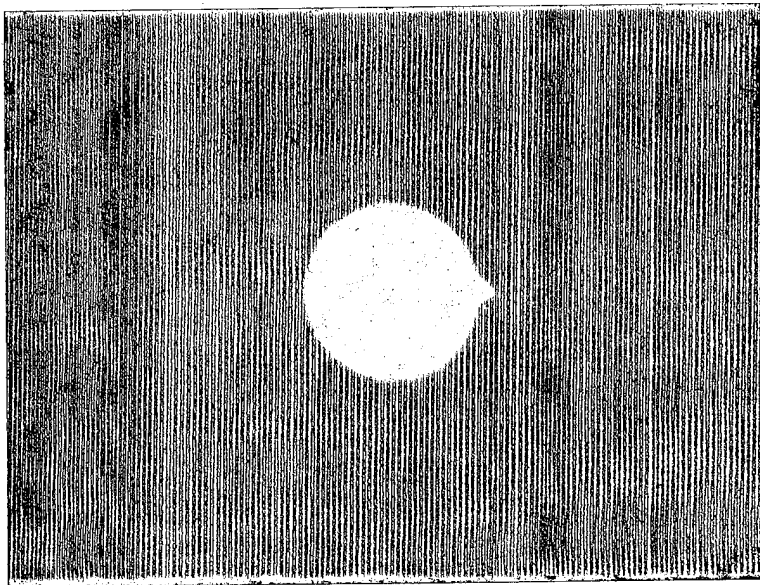
SPECIMEN NUMBER L1-10-31

5/8 HALF PENETRATION SLIT

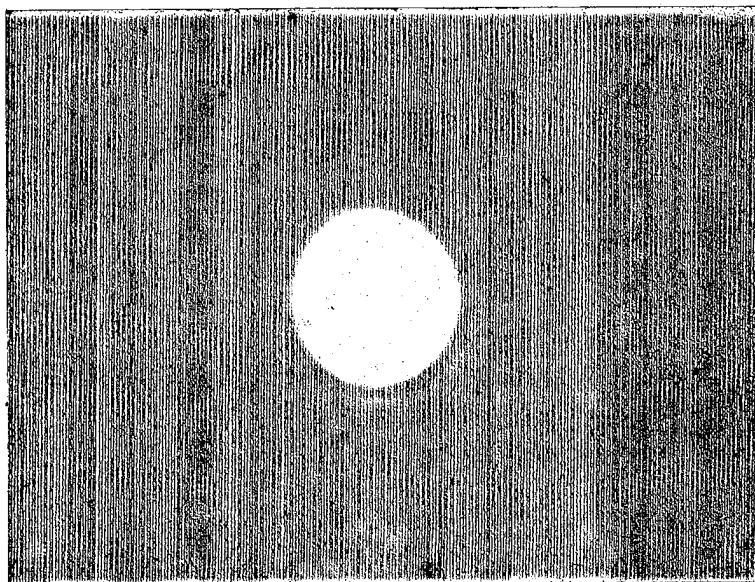


AFTER CYCLIC TEST

10⁵ CYCLES



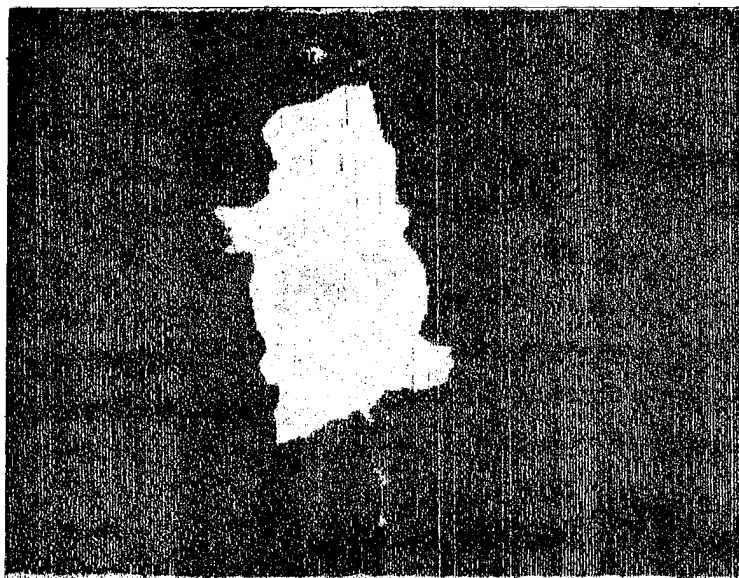
BEFORE TEST
SPECIMEN NUMBER L1-10-32
5/8 COUNTERSINK HOLE



BEFORE TEST

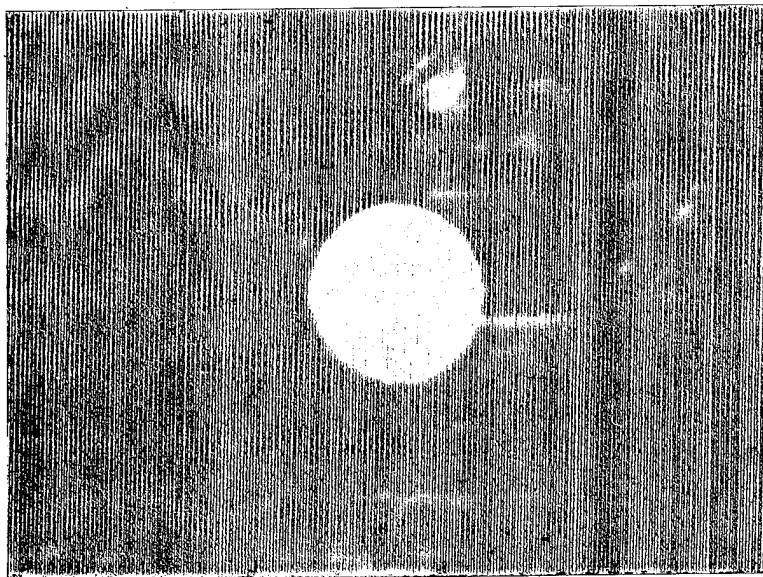
SPECIMEN NUMBER L1-10-33

5/8 COUNTERSINK HOLE

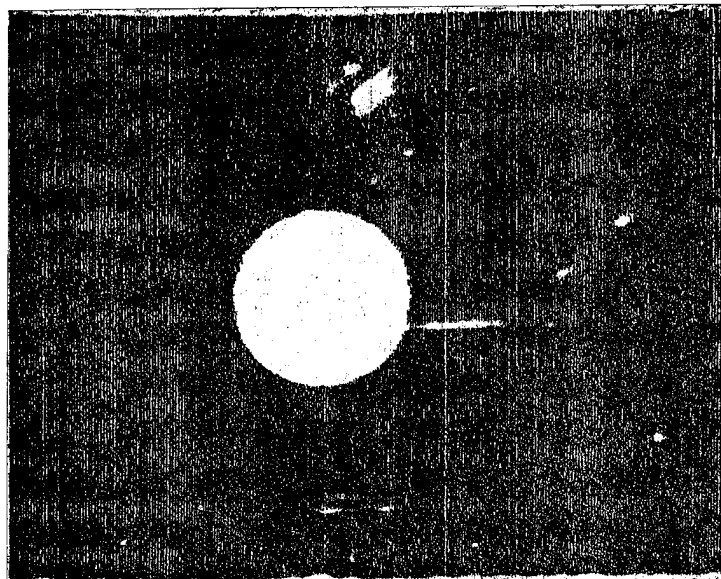


AFTER CYCLIC TEST

1.5×10^6 CYCLES



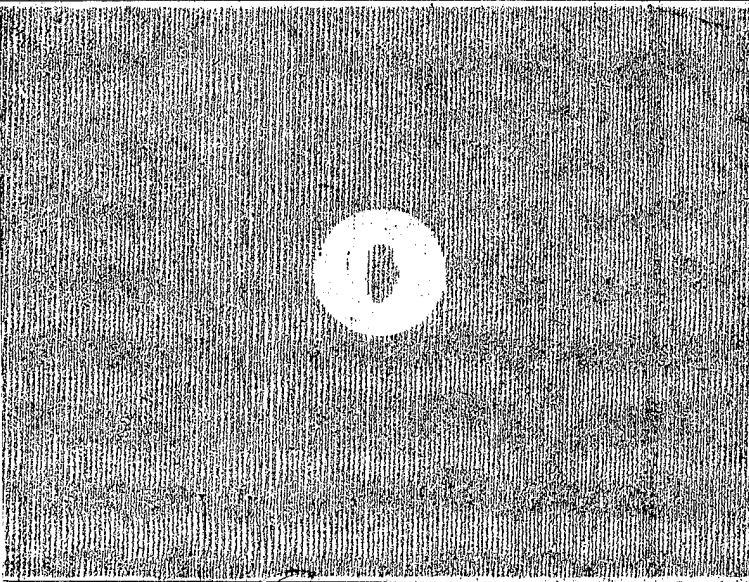
BEFORE TEST



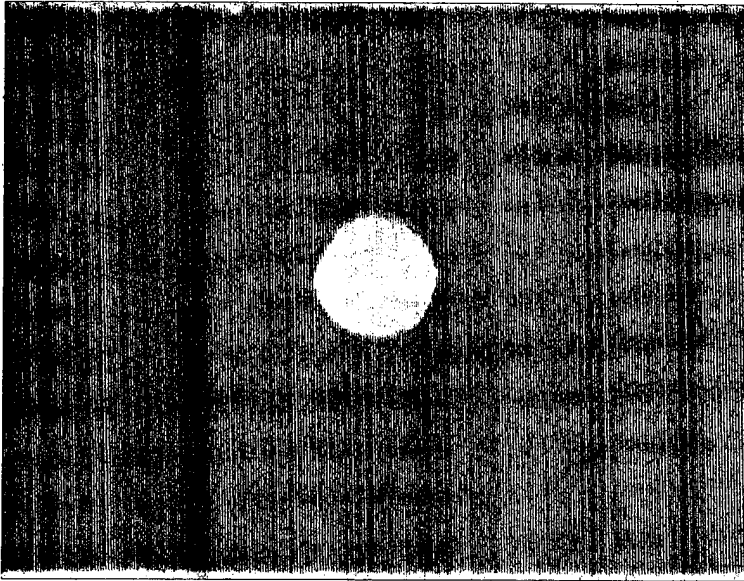
AFTER PRELOAD

SPECIMEN NUMBER L1-10-34

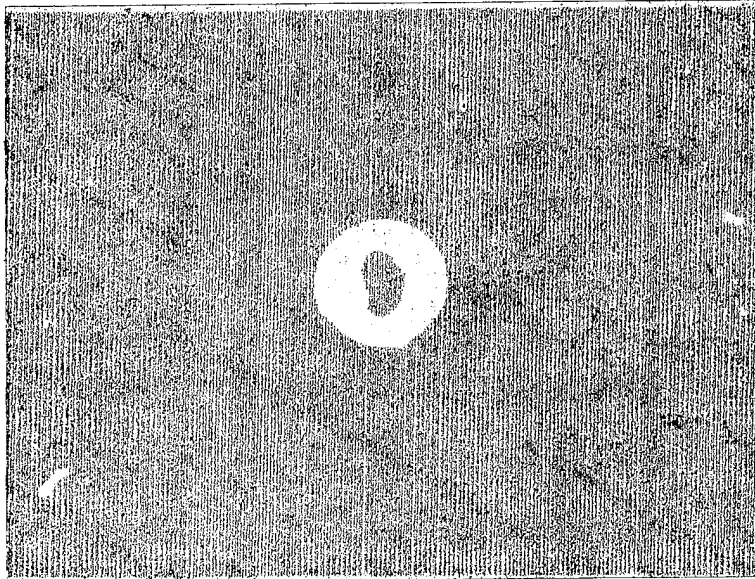
5/8 COUNTERSINK HOLE



BEFORE TEST
SPECIMEN NUMBER L1-11-1
5/8 DISBOND DEFECT



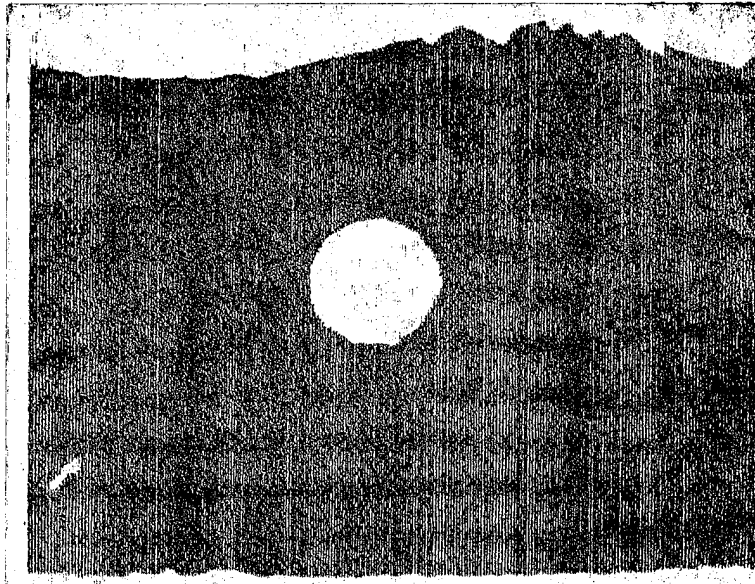
AFTER CYCLIC TEST
10² CYCLES



BEFORE TEST

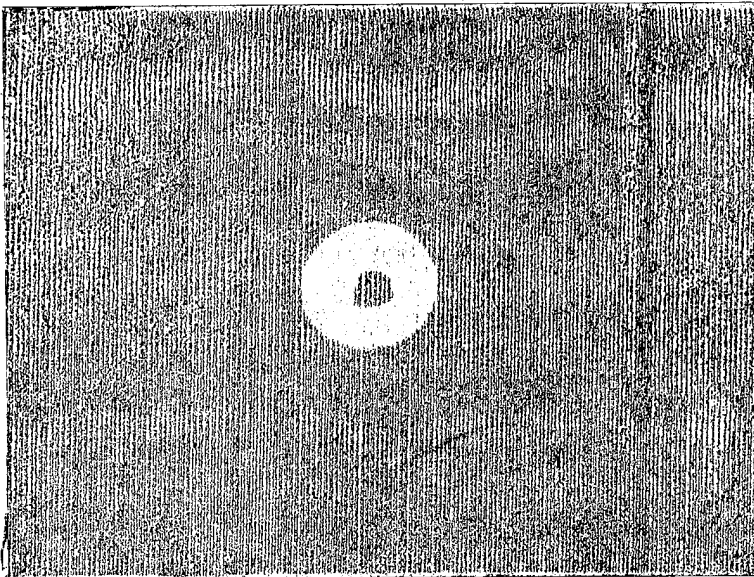
SPECIMEN NUMBER L1-11-2

5/8 DISBOND DEFECT



AFTER CYCLIC TEST

15 780 CYCLES



BEFORE TEST

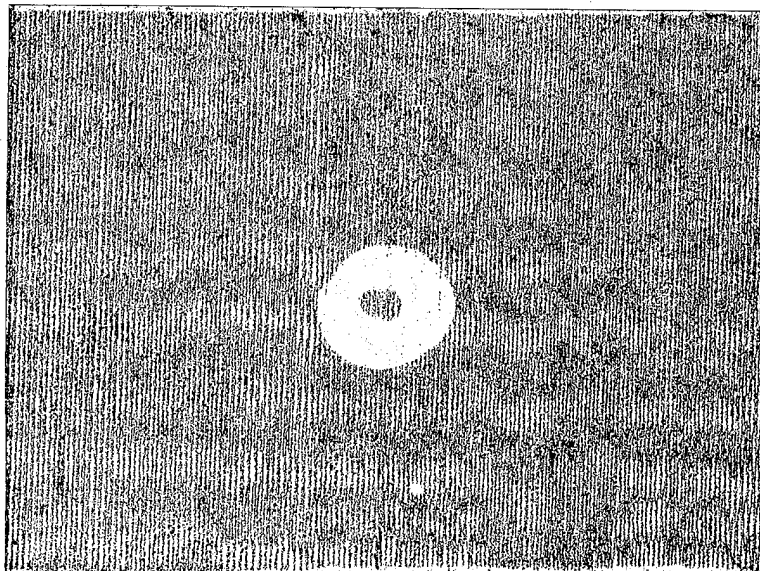
SPECIMEN NUMBER L1-11-3

5/8 DISBOND DEFECT



AFTER CYCLIC TEST

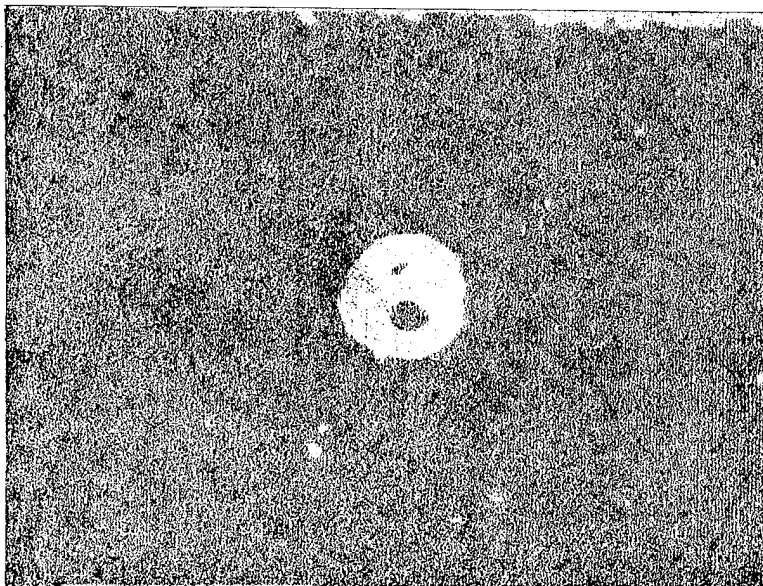
77 CYCLES



BEFORE TEST

SPECIMEN L1-11-4

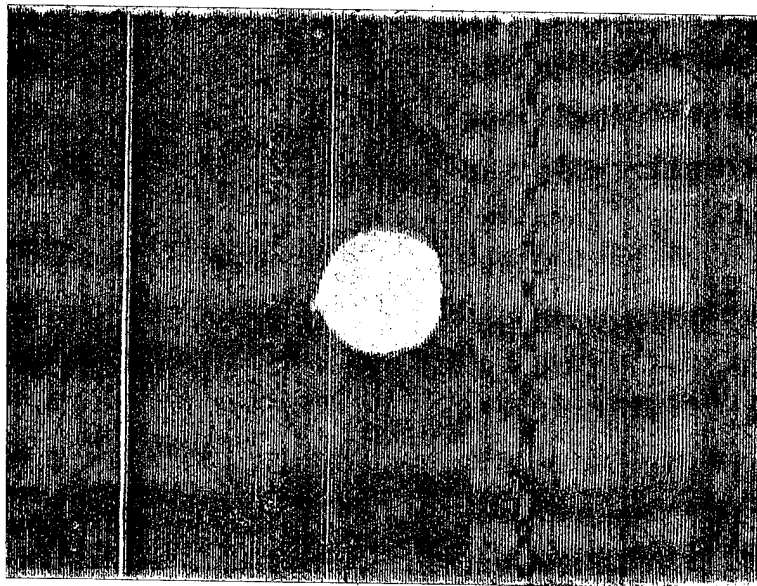
5/8 DISBOND DEFECT



BEFORE TEST

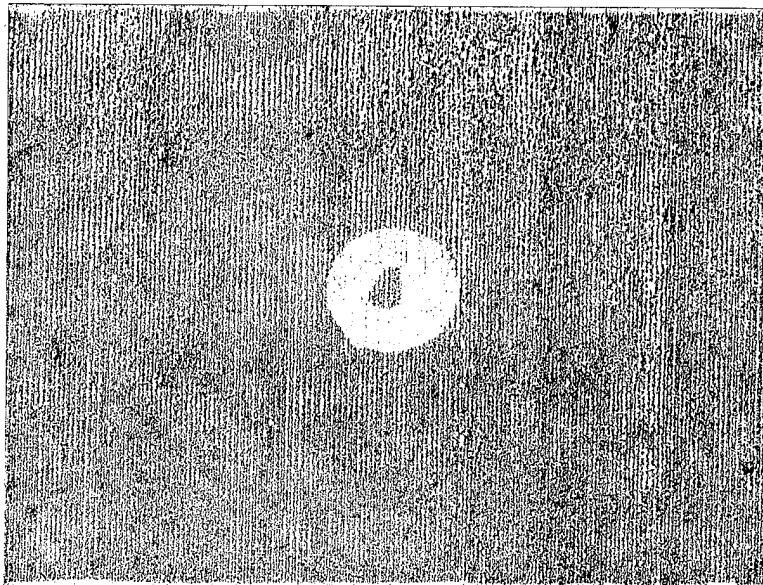
SPECIMEN NUMBER L1-11-5

5/8 DISBOND DEFECT



AFTER CYCLIC TEST

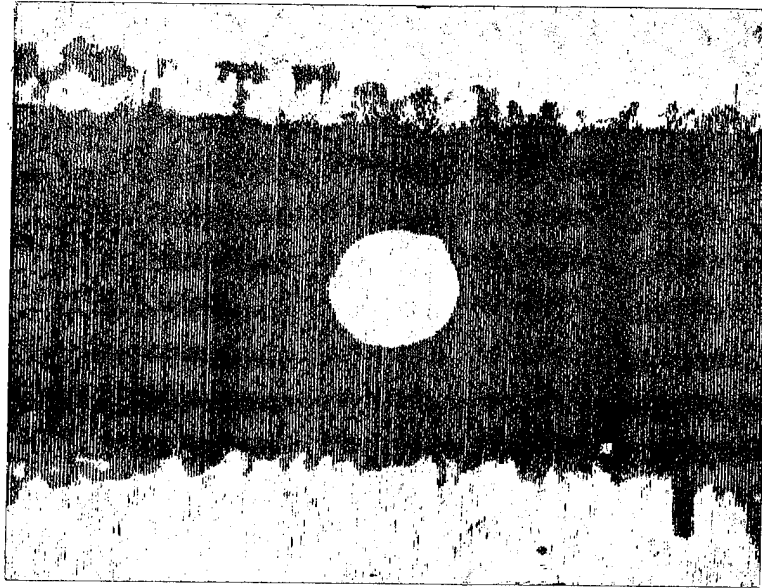
10^2 CYCLES



BEFORE TEST

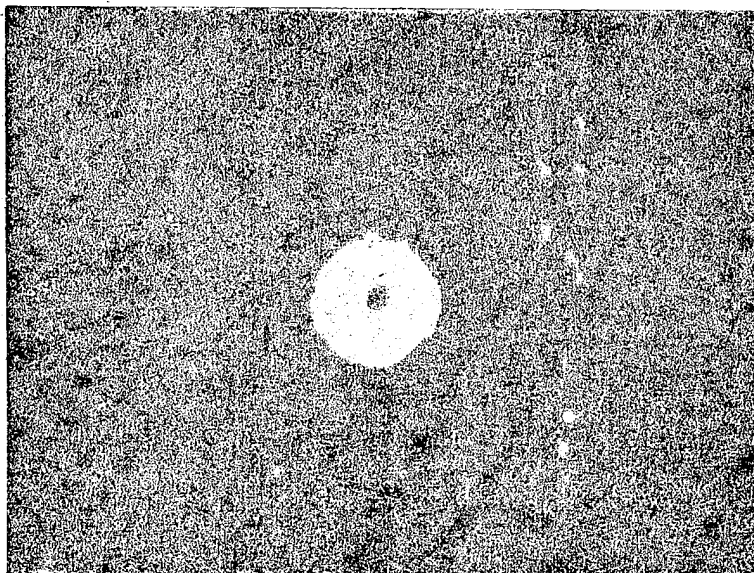
SPECIMEN NUMBER L1-11-6

5/8 DISBOND DEFECT



AFTER CYCLIC TEST

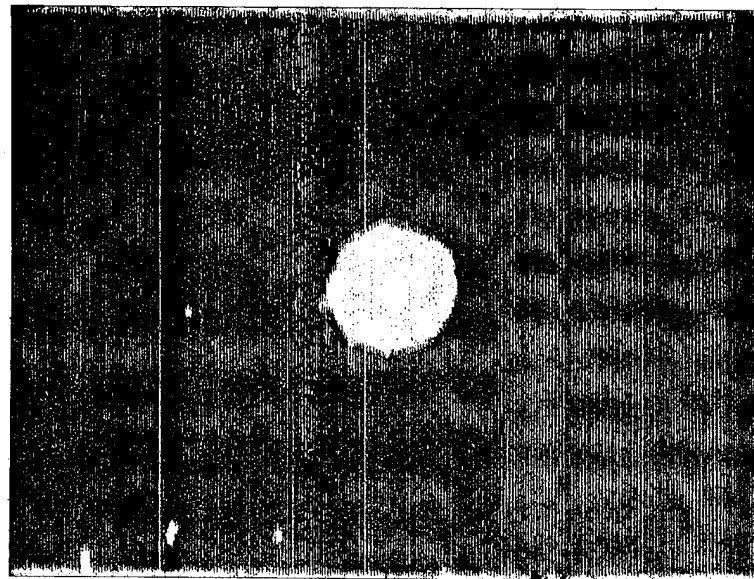
1.5 x 10⁶ CYCLES



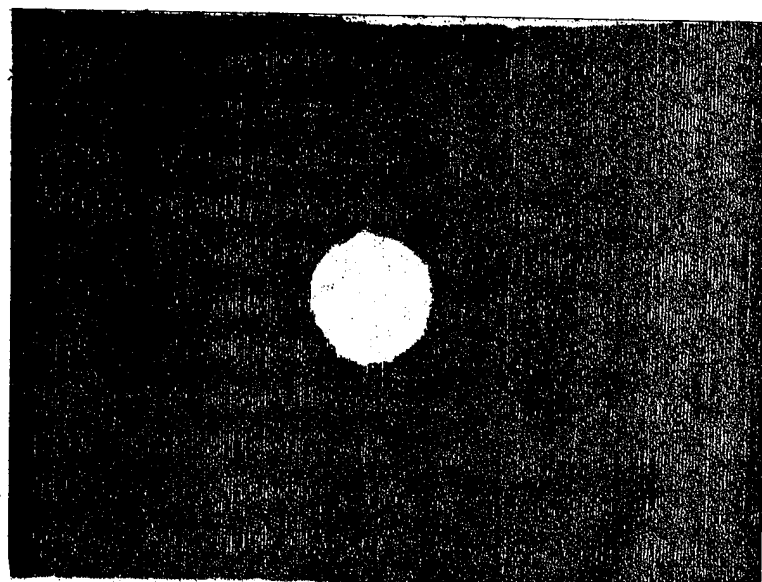
BEFORE TEST

SPECIMEN NUMBER L1-11-7

5/8 DISBOND DEFECT



AFTER PRELOAD



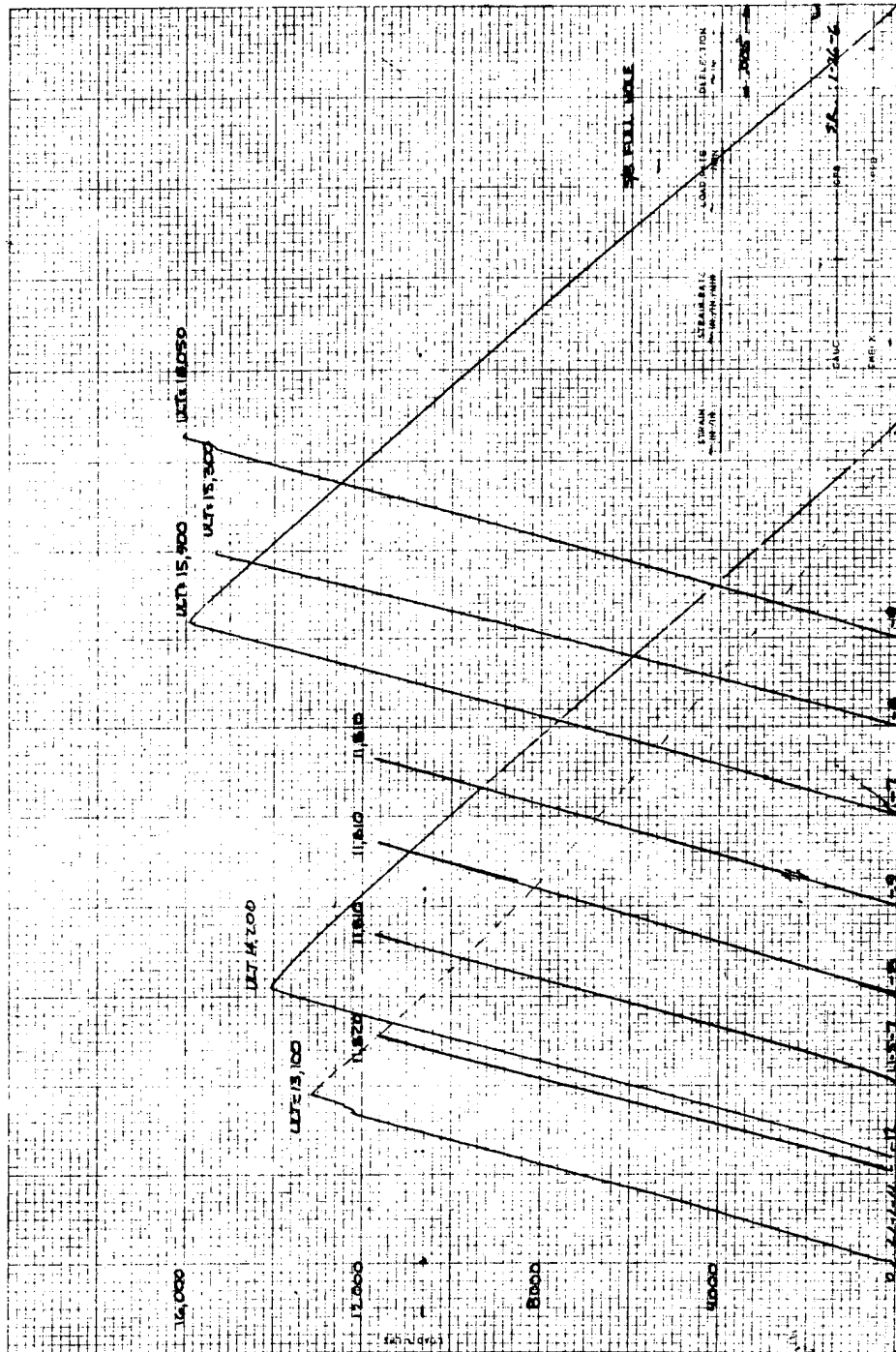
AFTER CYCLIC TEST

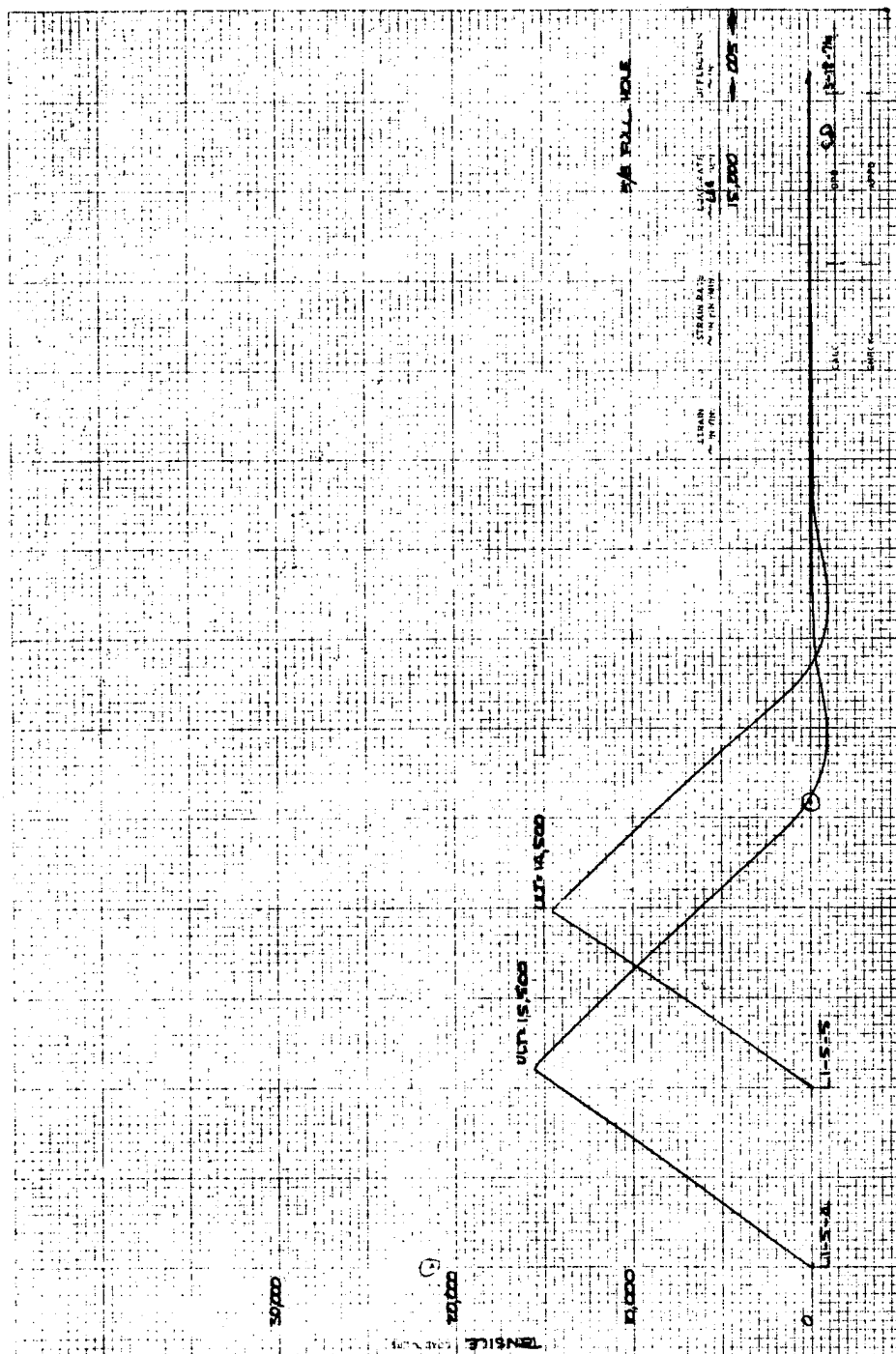
10^2 CYCLES

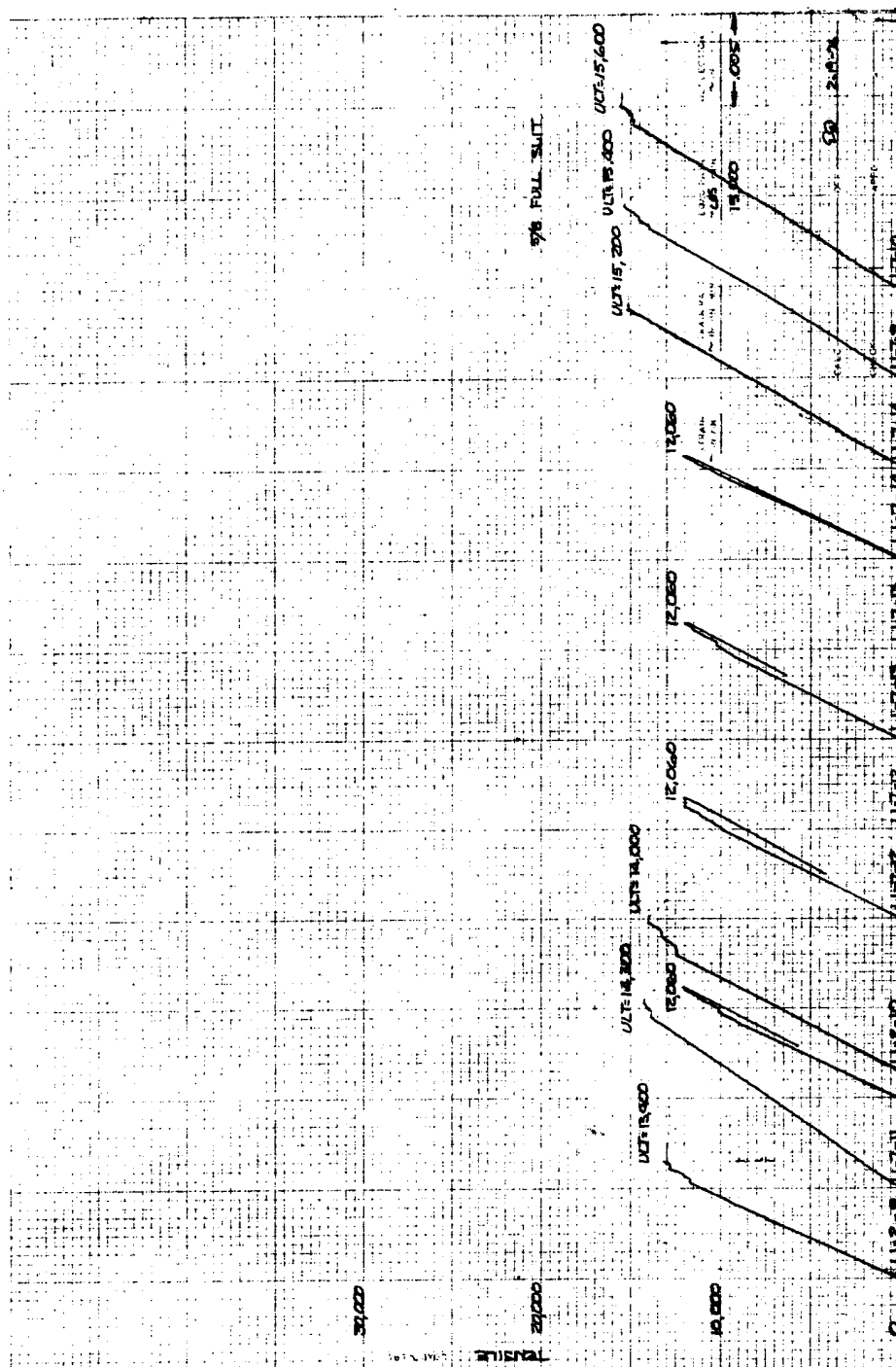
APPENDIX C

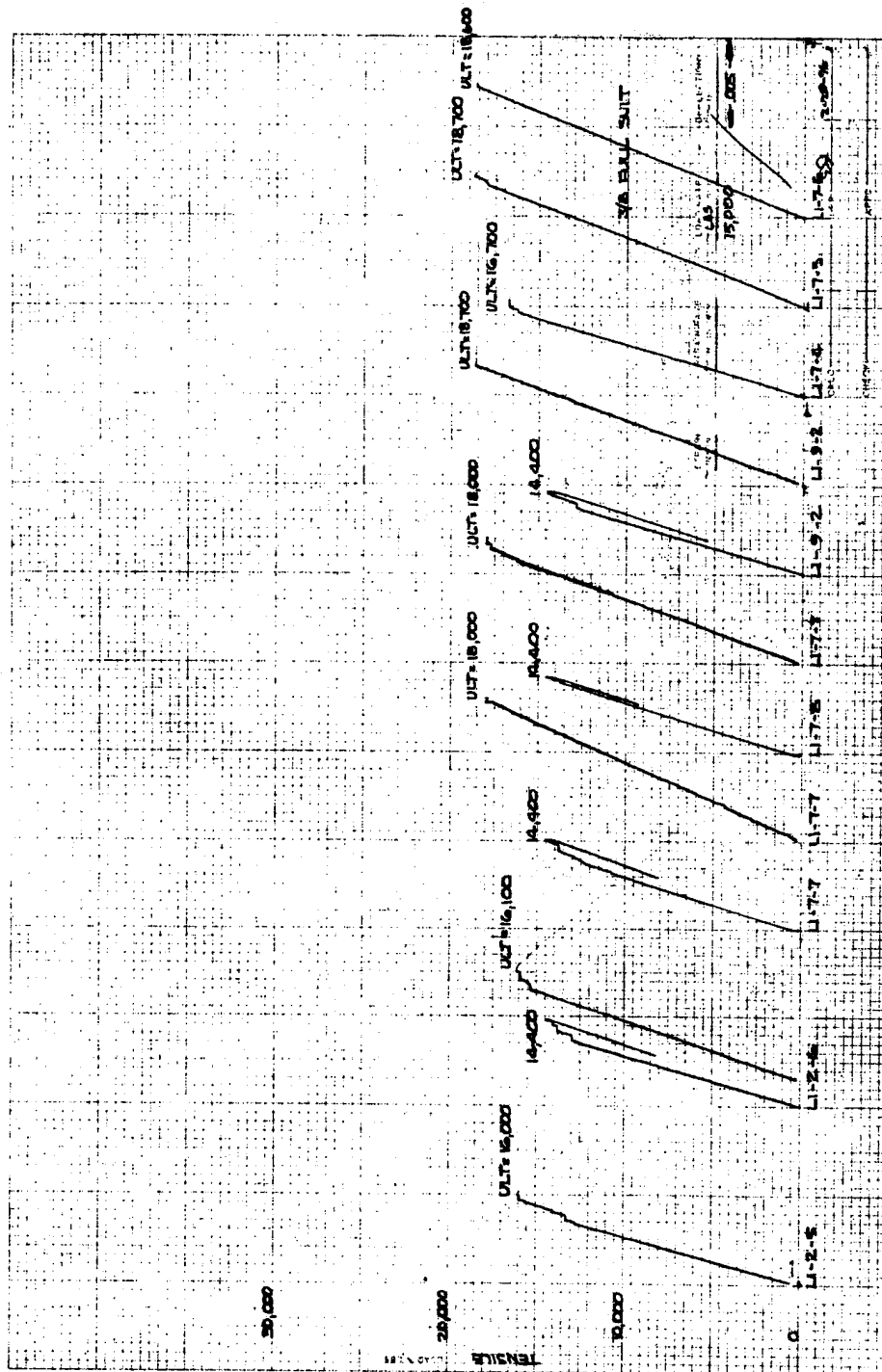
STATIC TEST CRACK OPENING DISPLACEMENT RECORDS

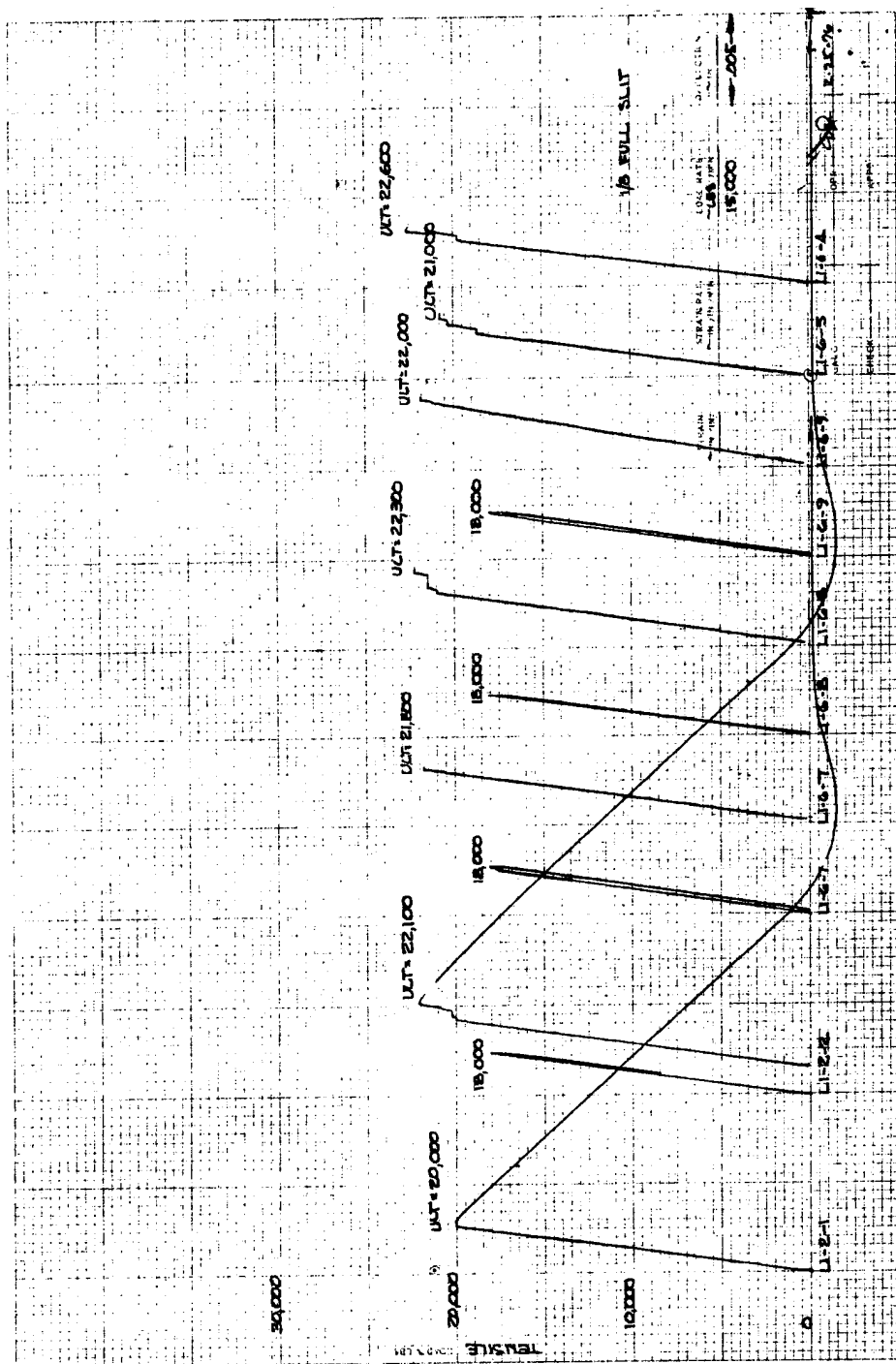
This appendix contains copies the machine records giving the crack opening displacement gage reading versus the static test machine load. Each page generally contains the records for all the static, preload and residual static tests for each defect configuration and laminate type. The curves are identified by specimen number and defect code. The value of the maximum test machine load as read from test machine dial is also recorded on the record. The letters ULT designate an ultimate or specimen failure load.

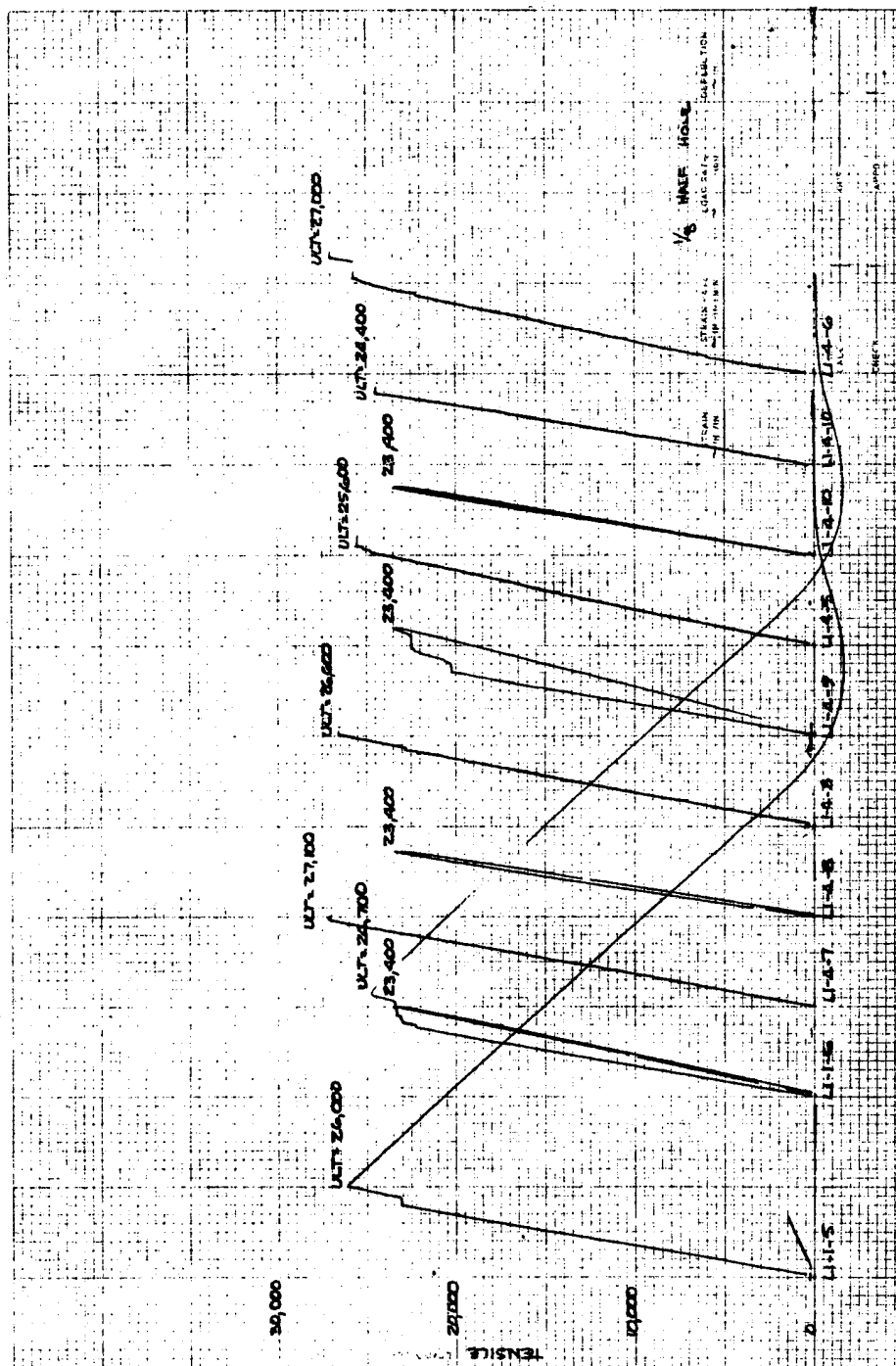








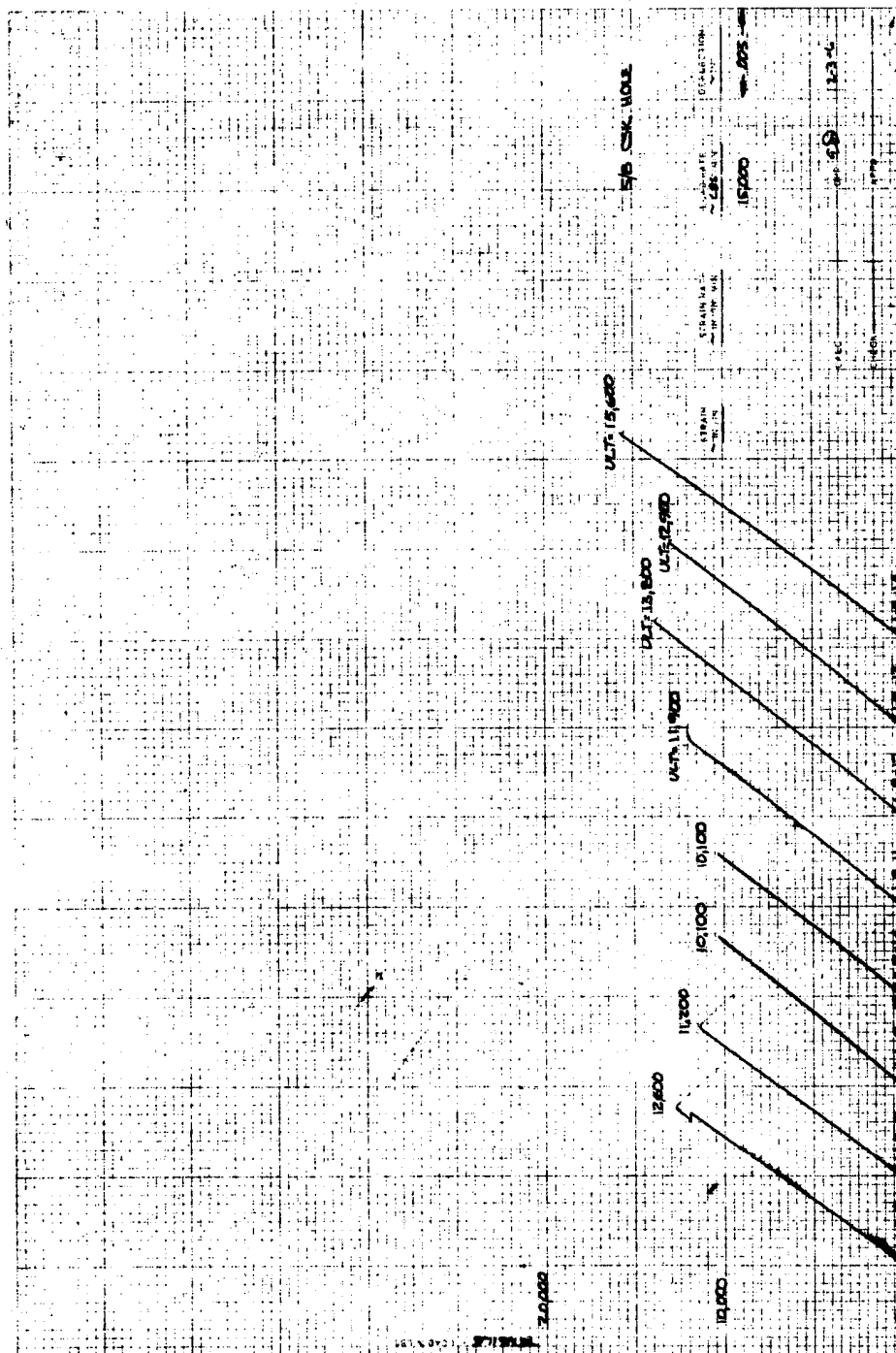


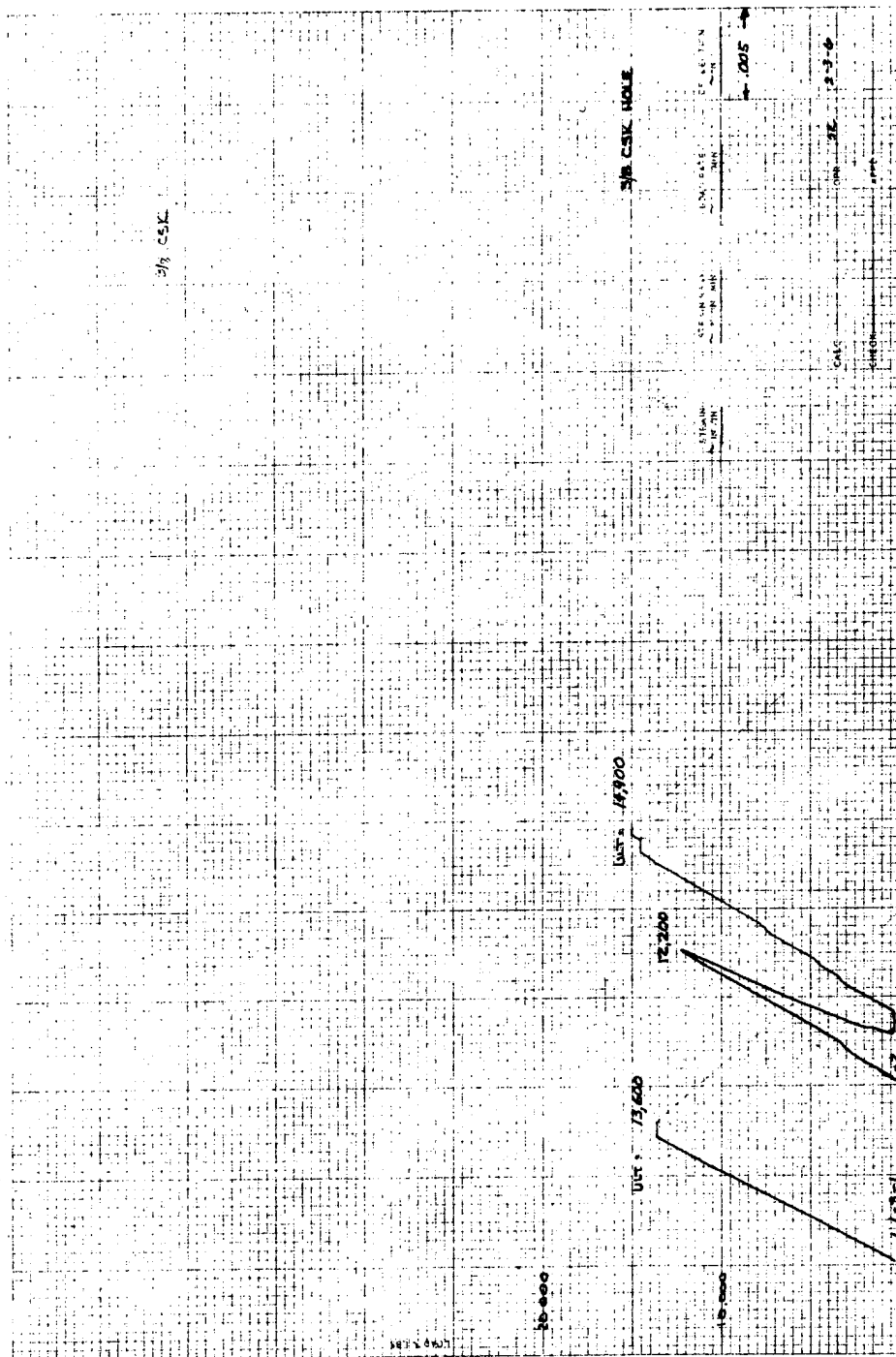




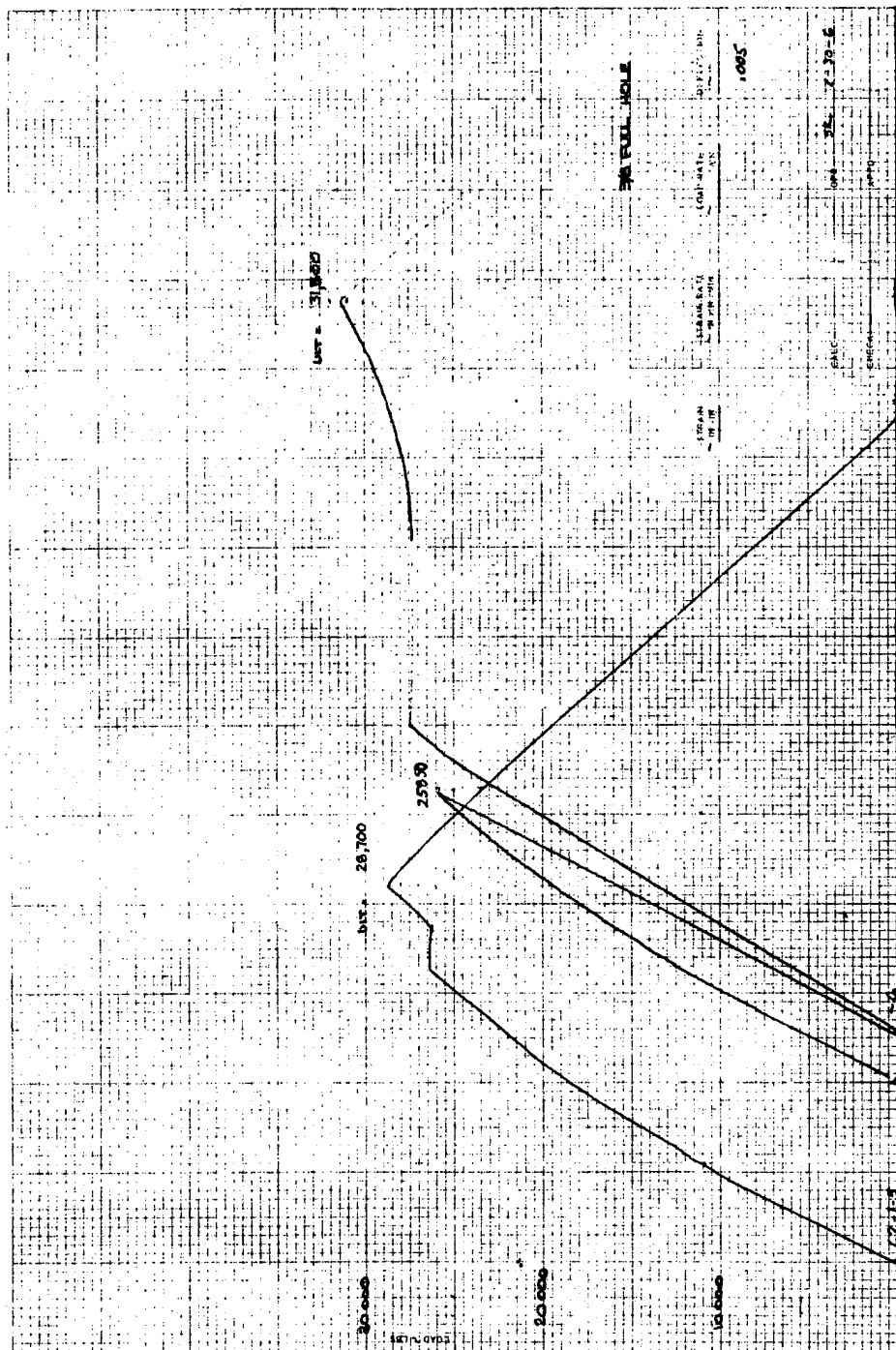




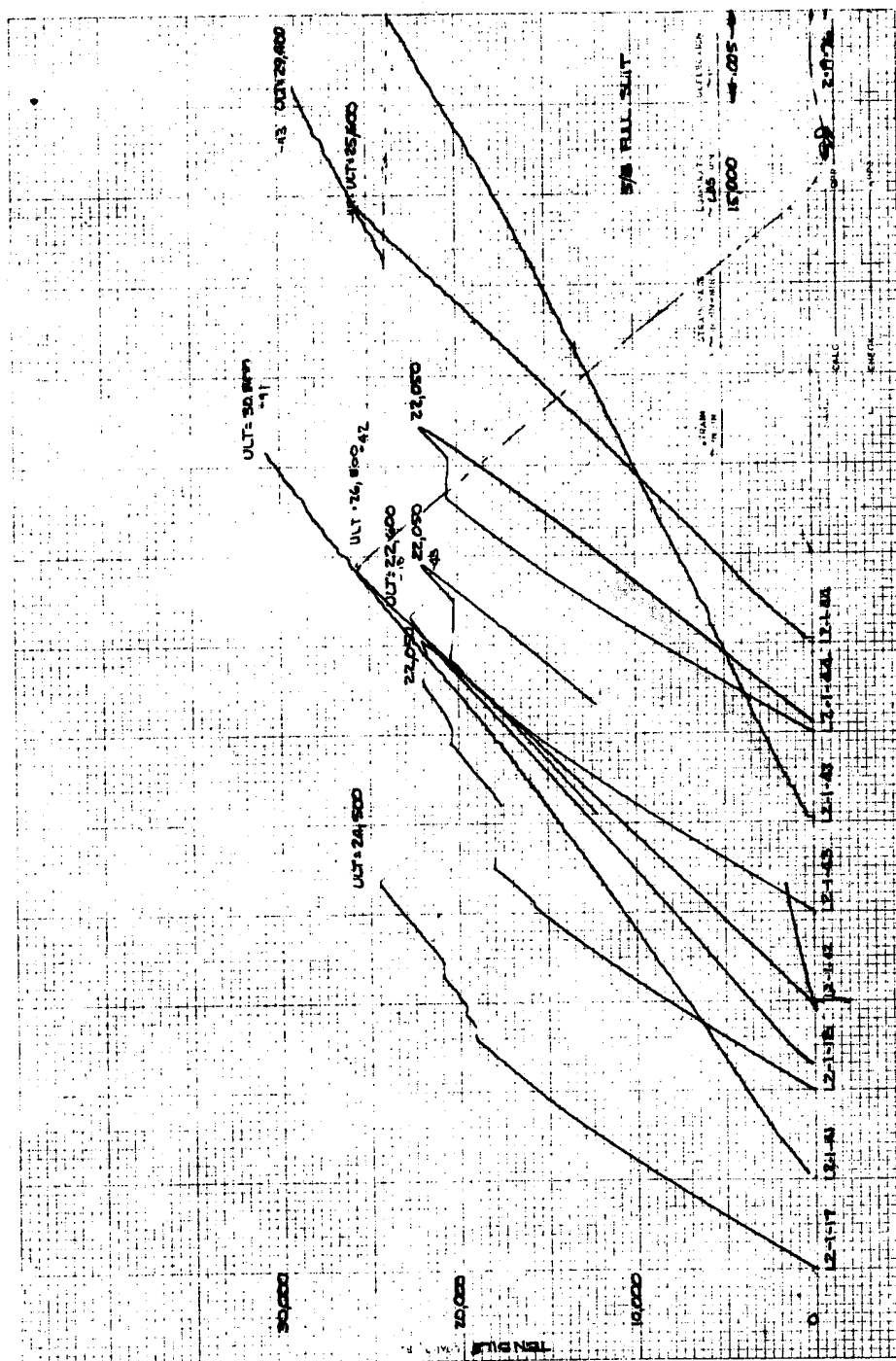


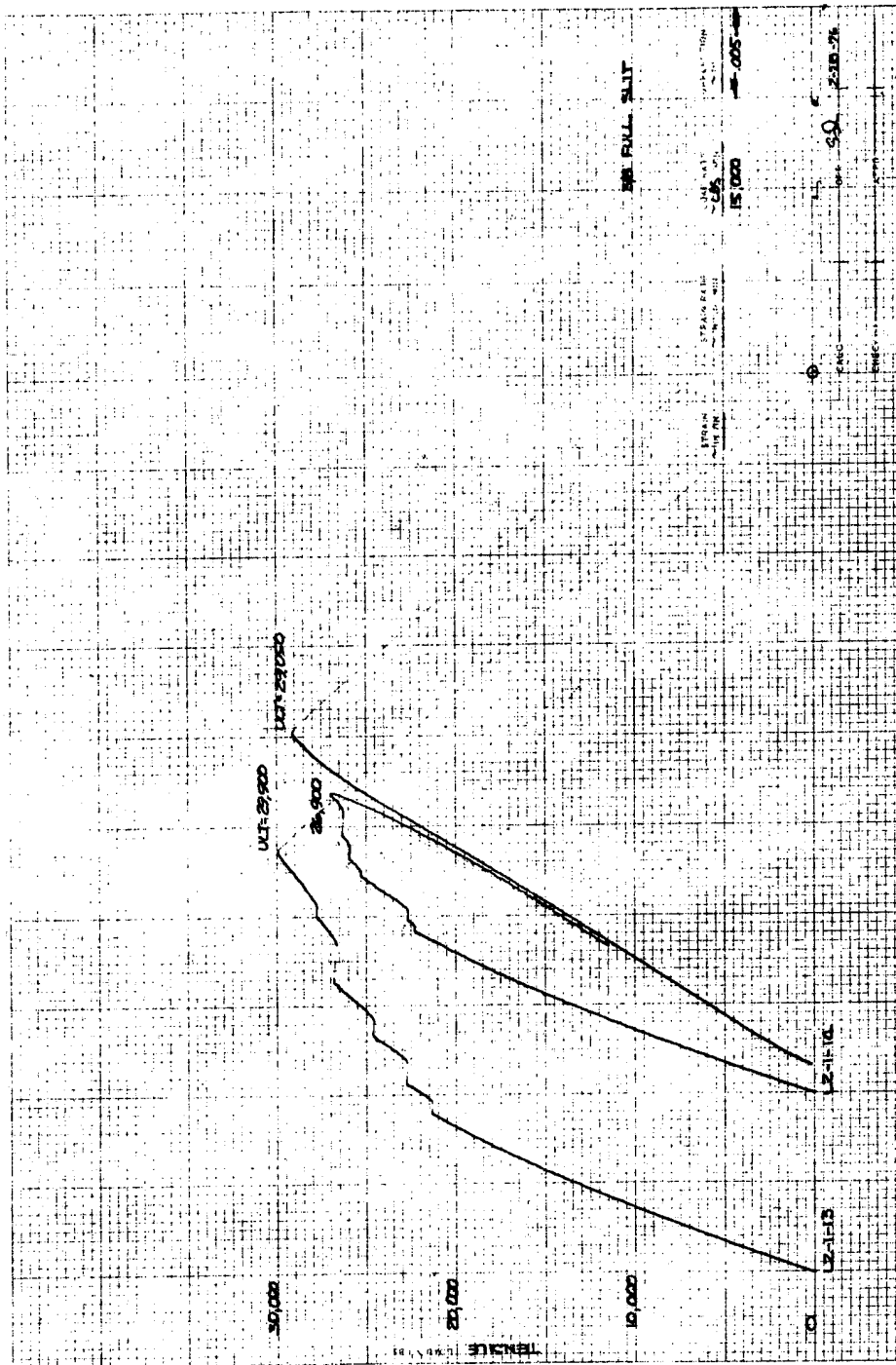




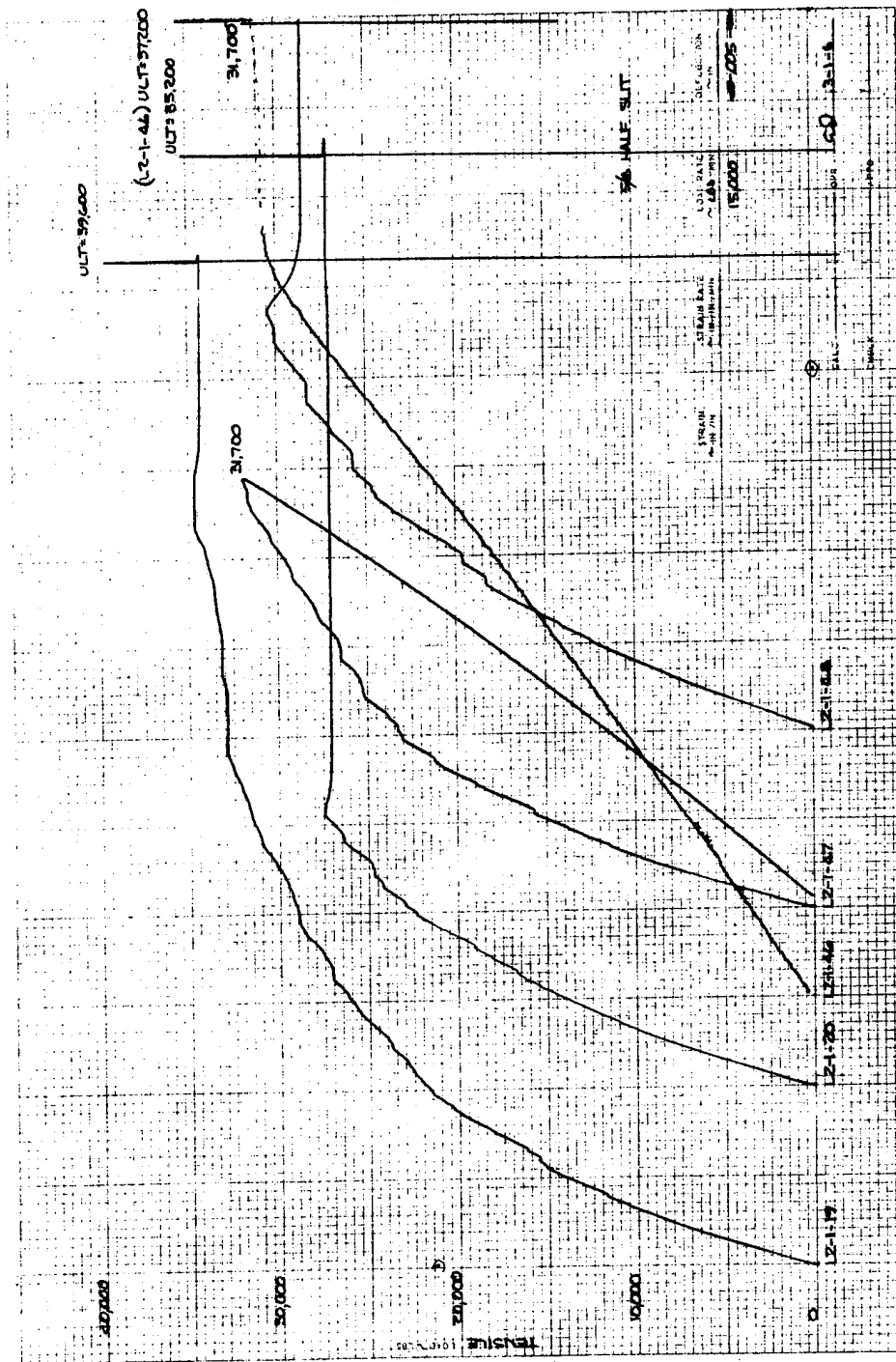


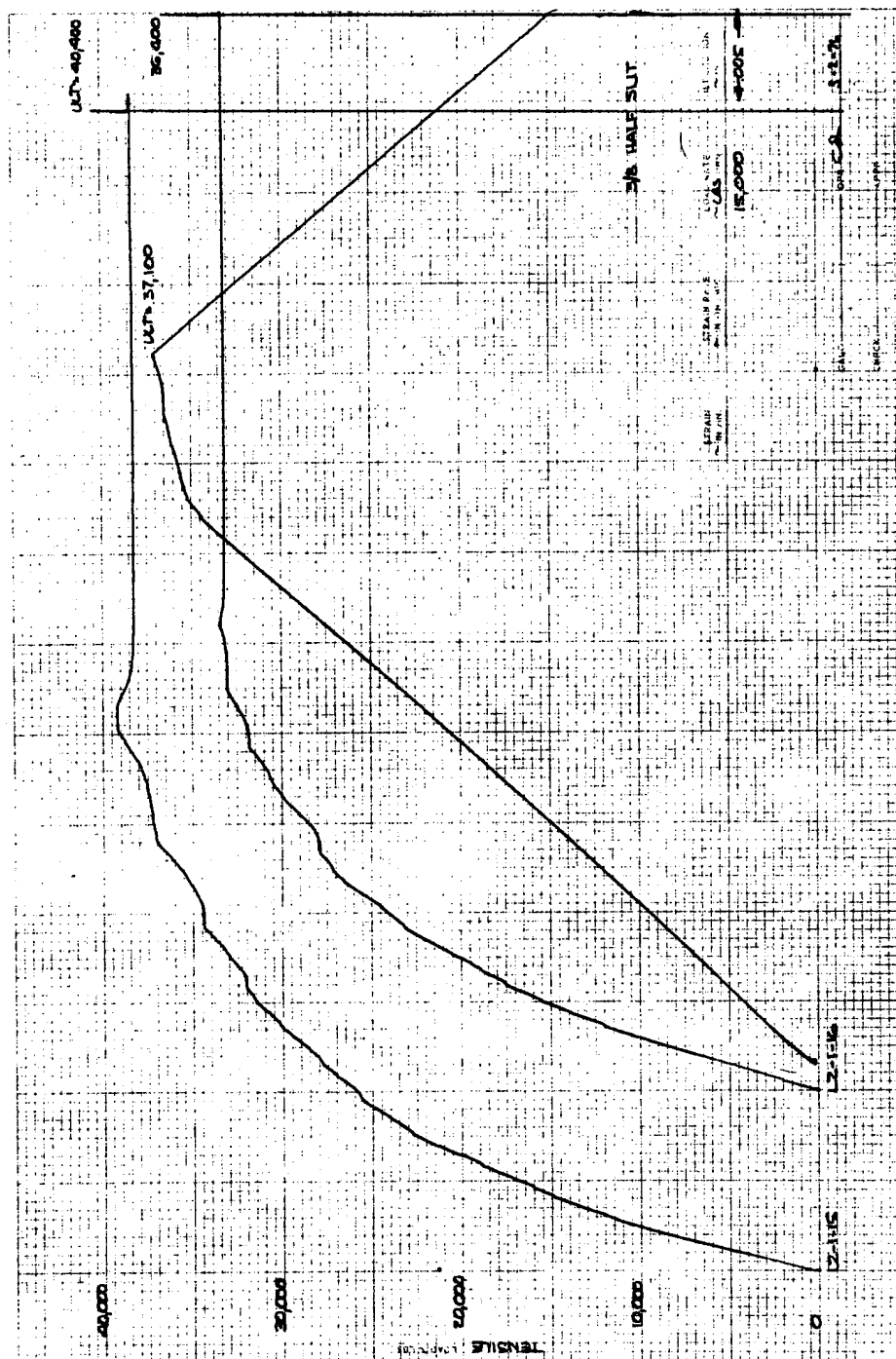


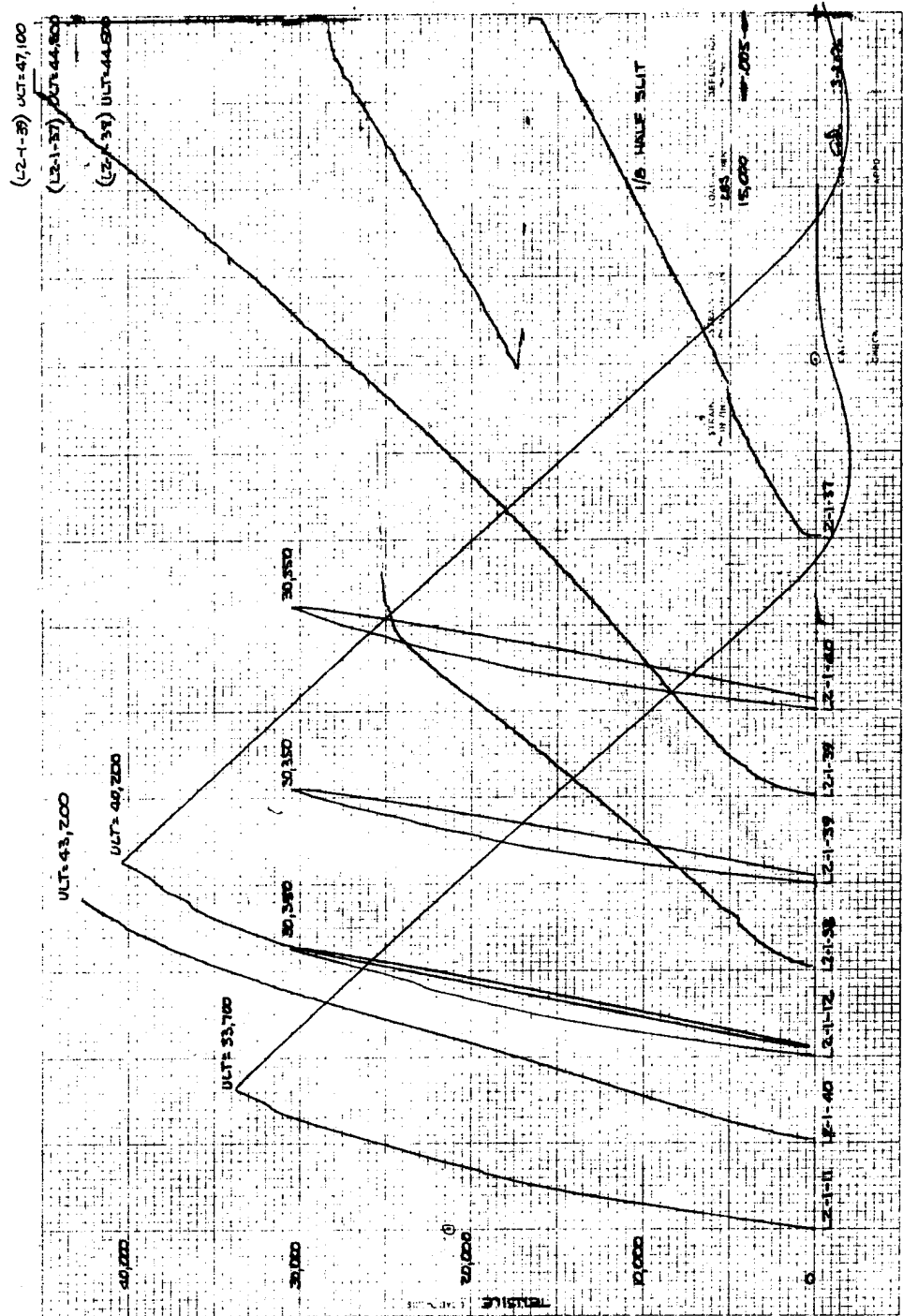


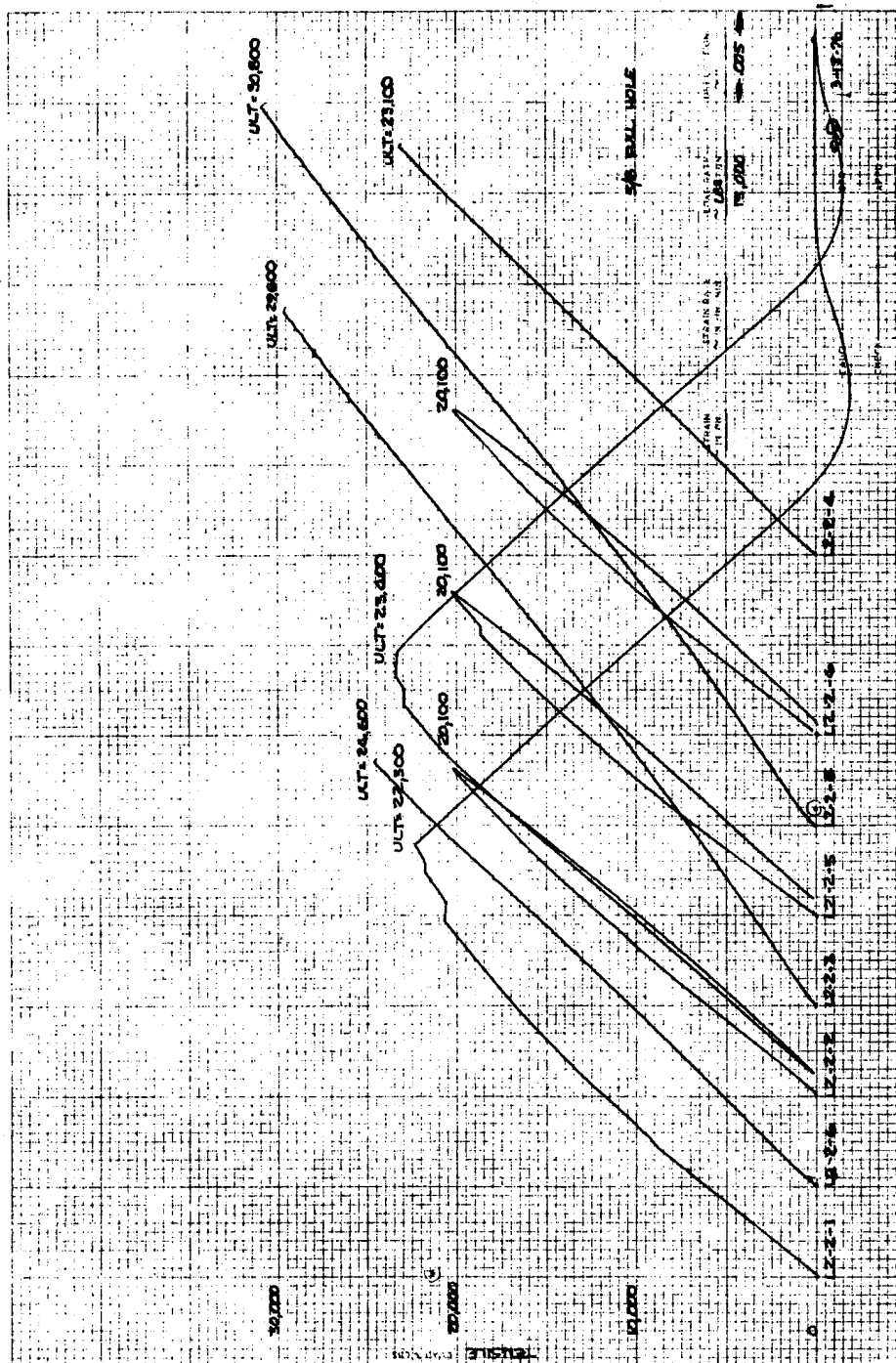


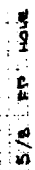


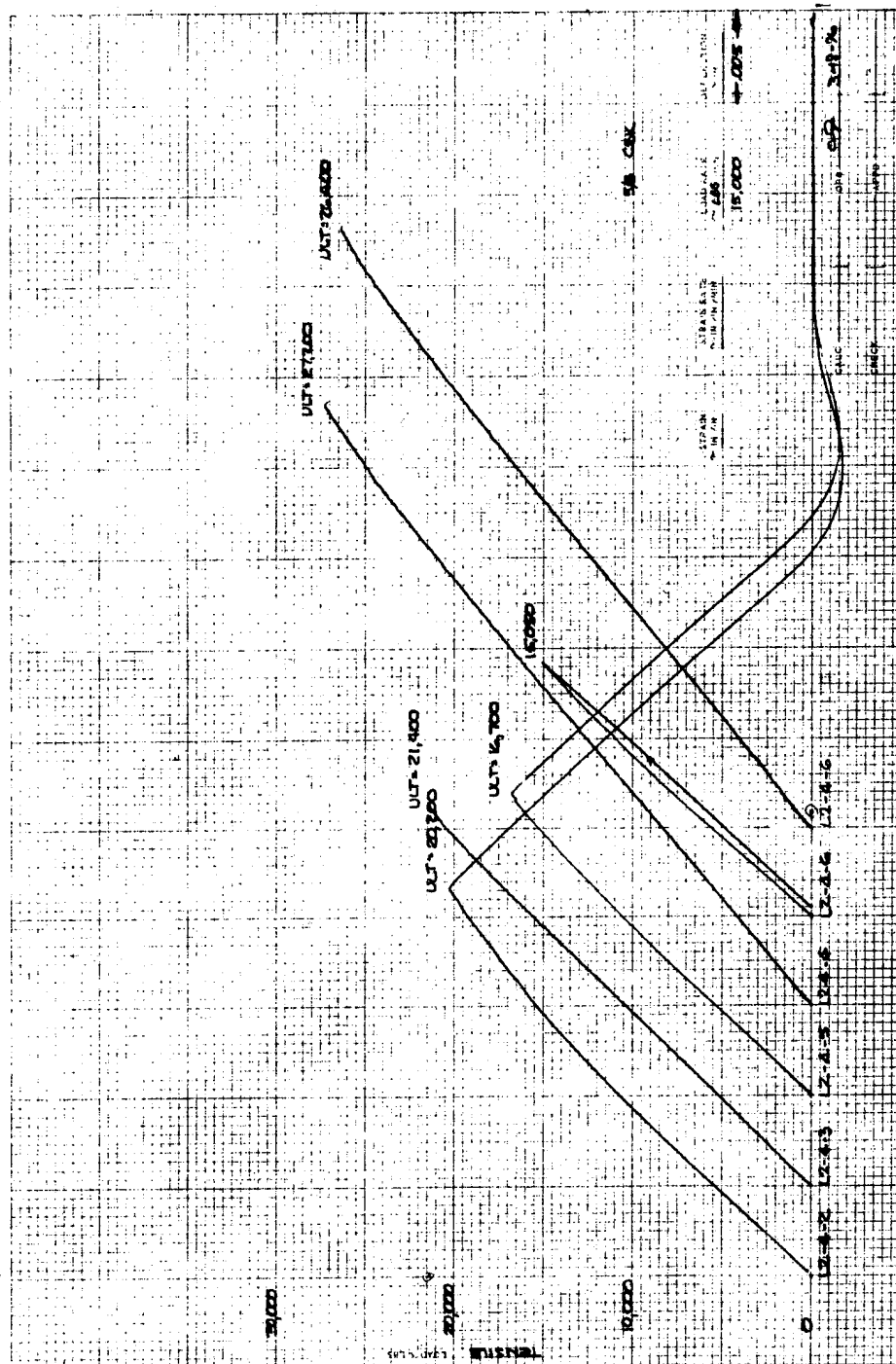


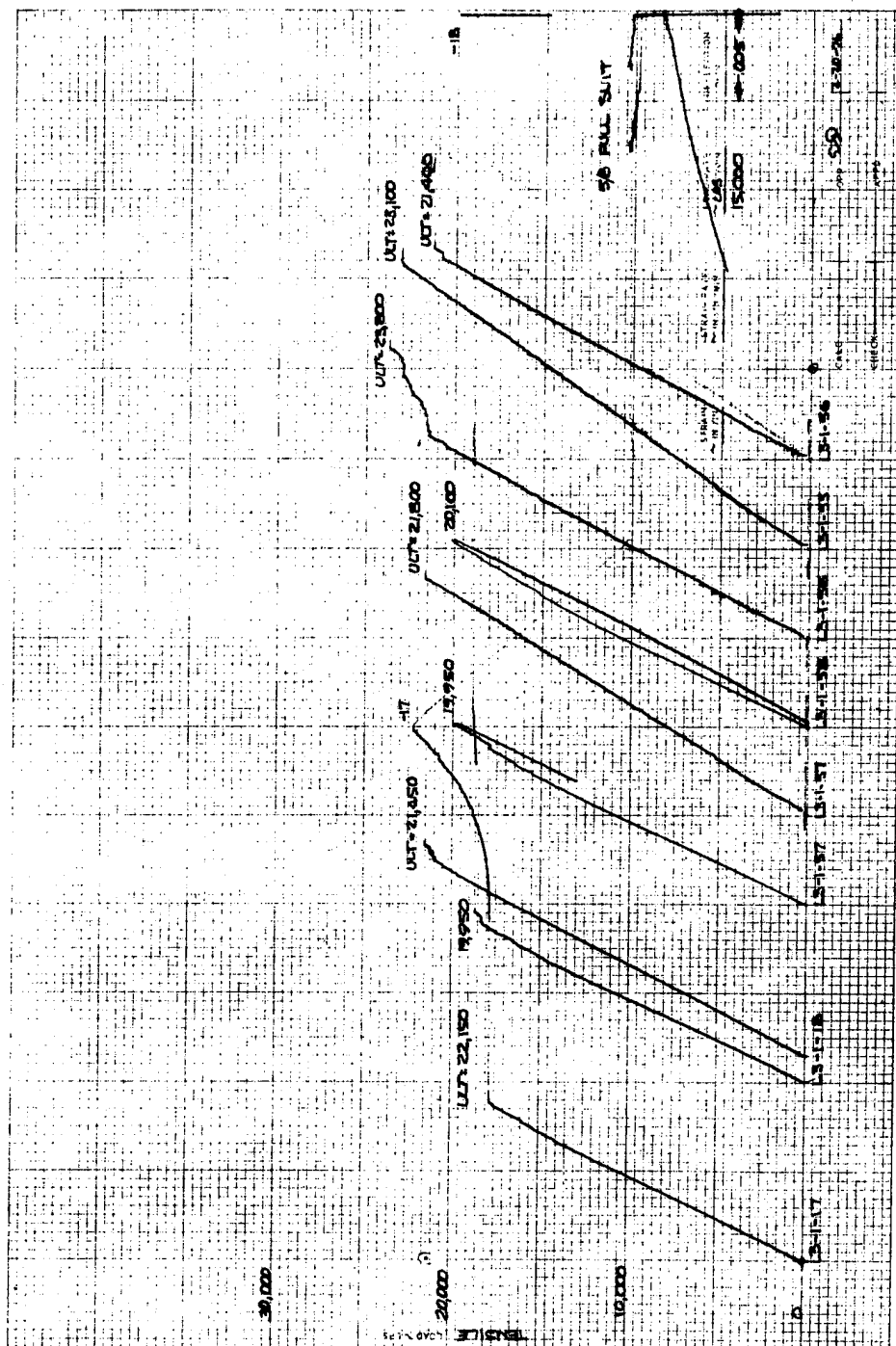


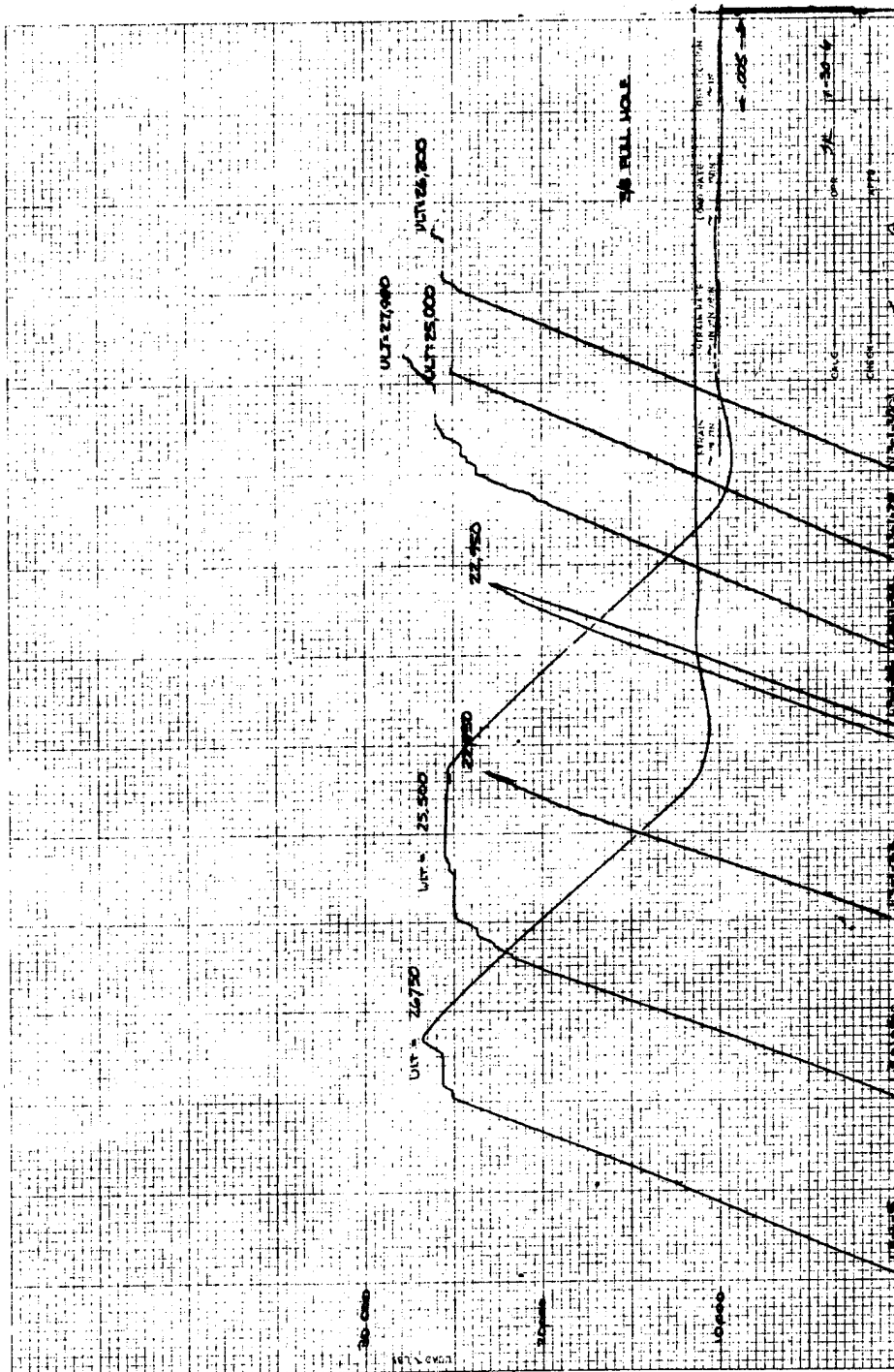


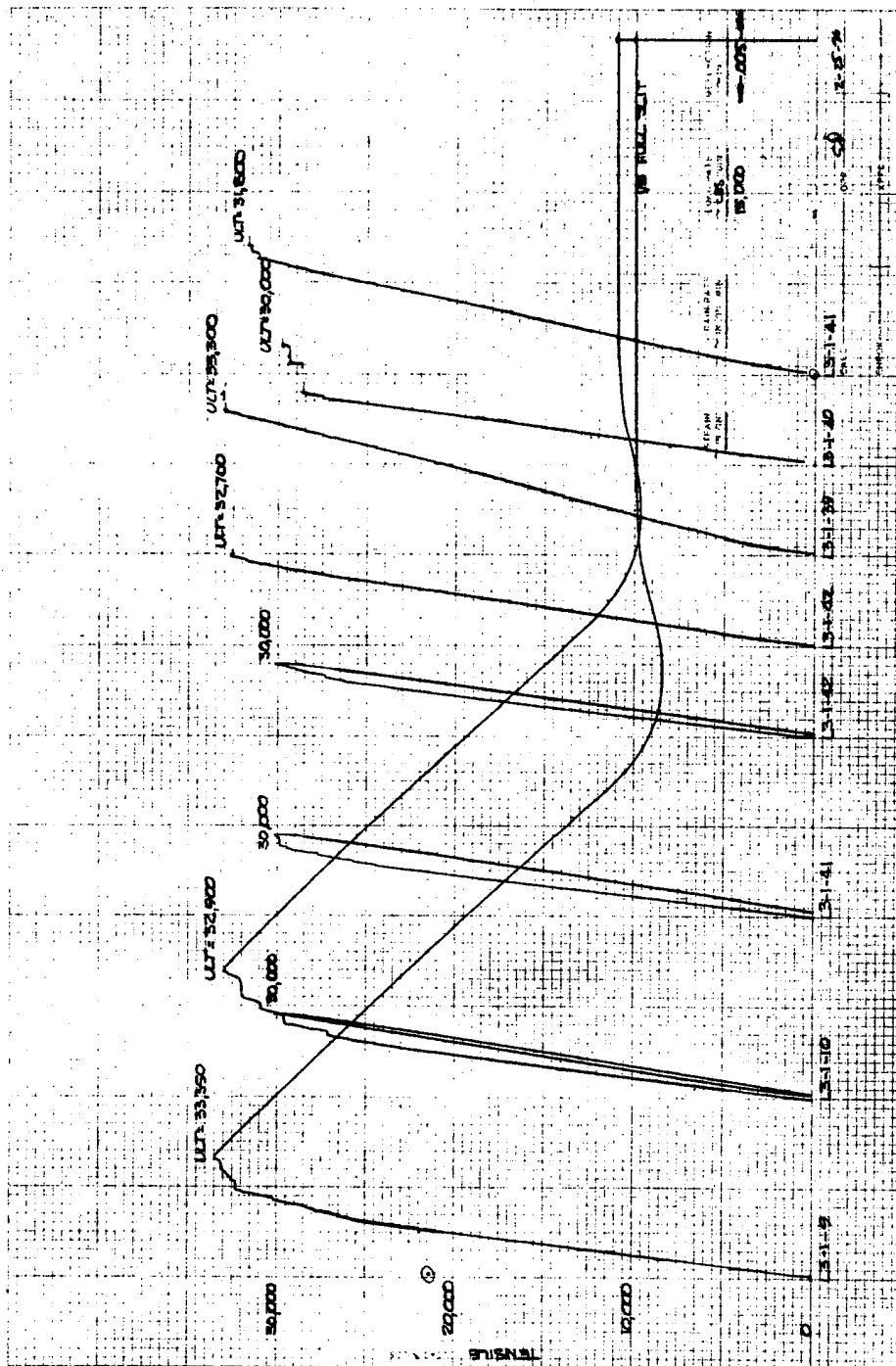


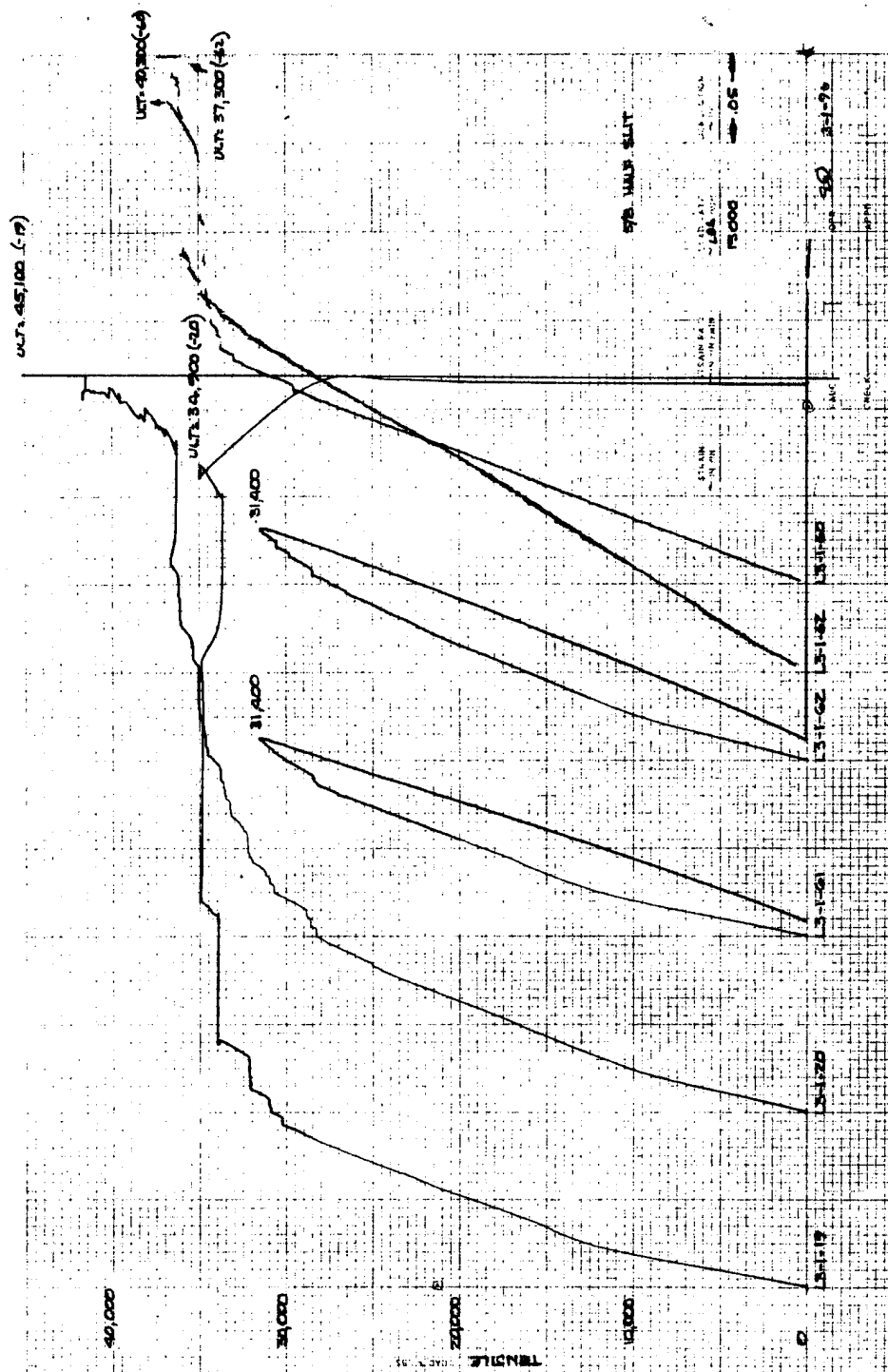


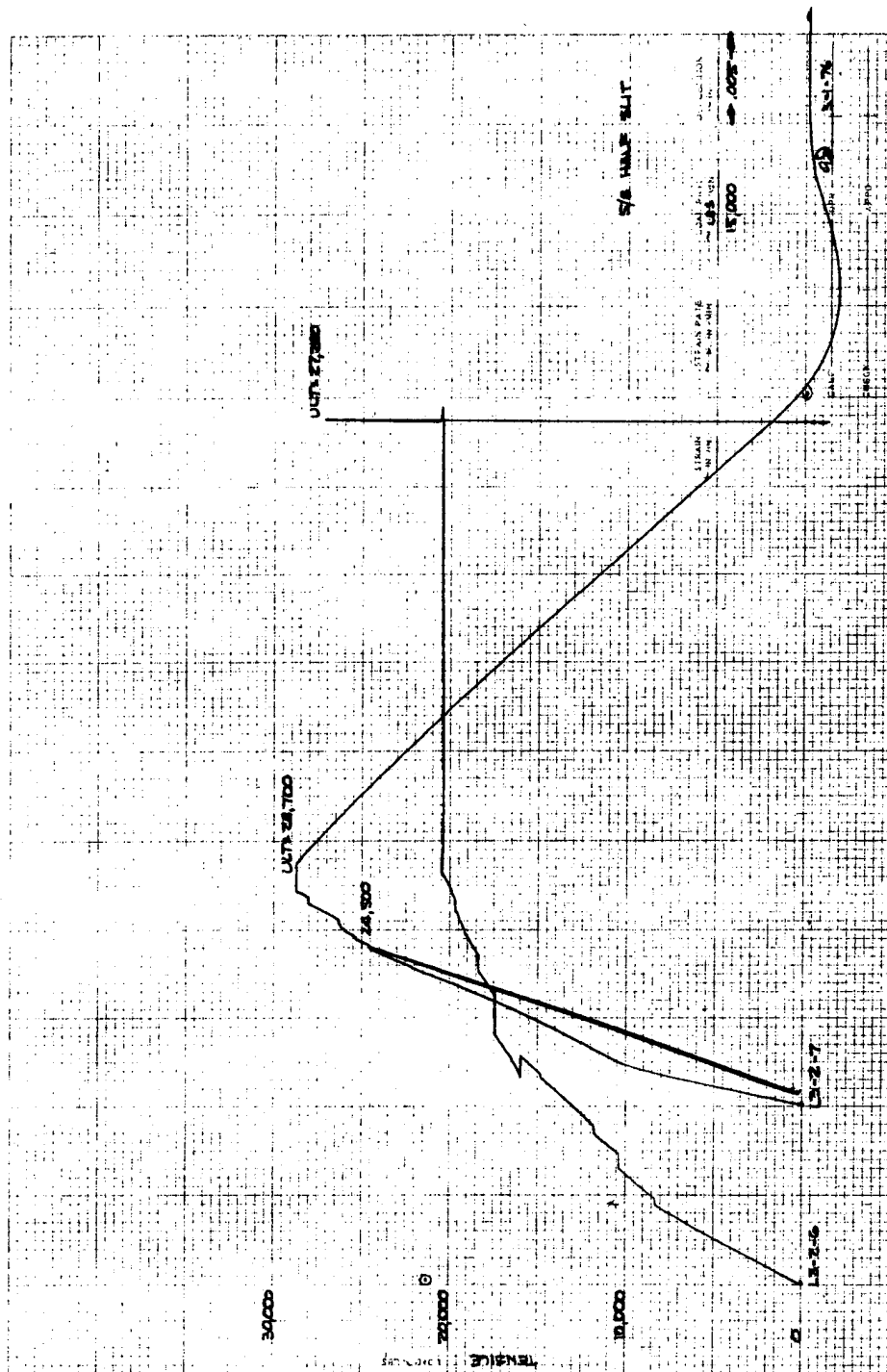


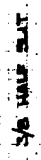


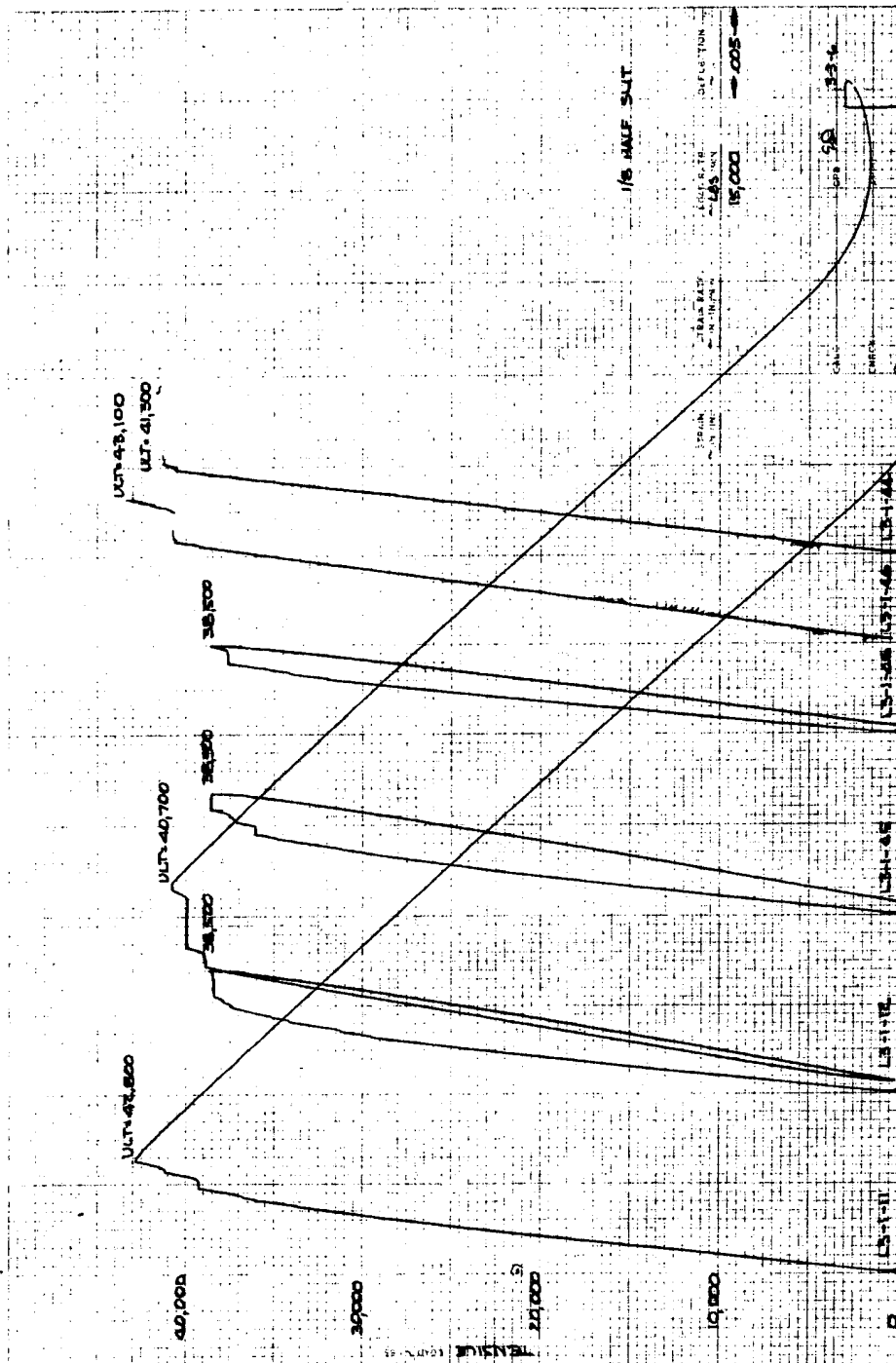












APPENDIX D

CYCLIC TEST CRACK OPENING DISPLACEMENT DATA

This appendix contains the results of crack opening displacement measurements made during cyclic loading. The total displacement measured during a cycle was divided by the stress excursion giving a "compliance" value. This data was recorded periodically during the cyclic test. All the results found for a particular defect type are given in each figure. Each figure is identified with the defect code and laminate type.

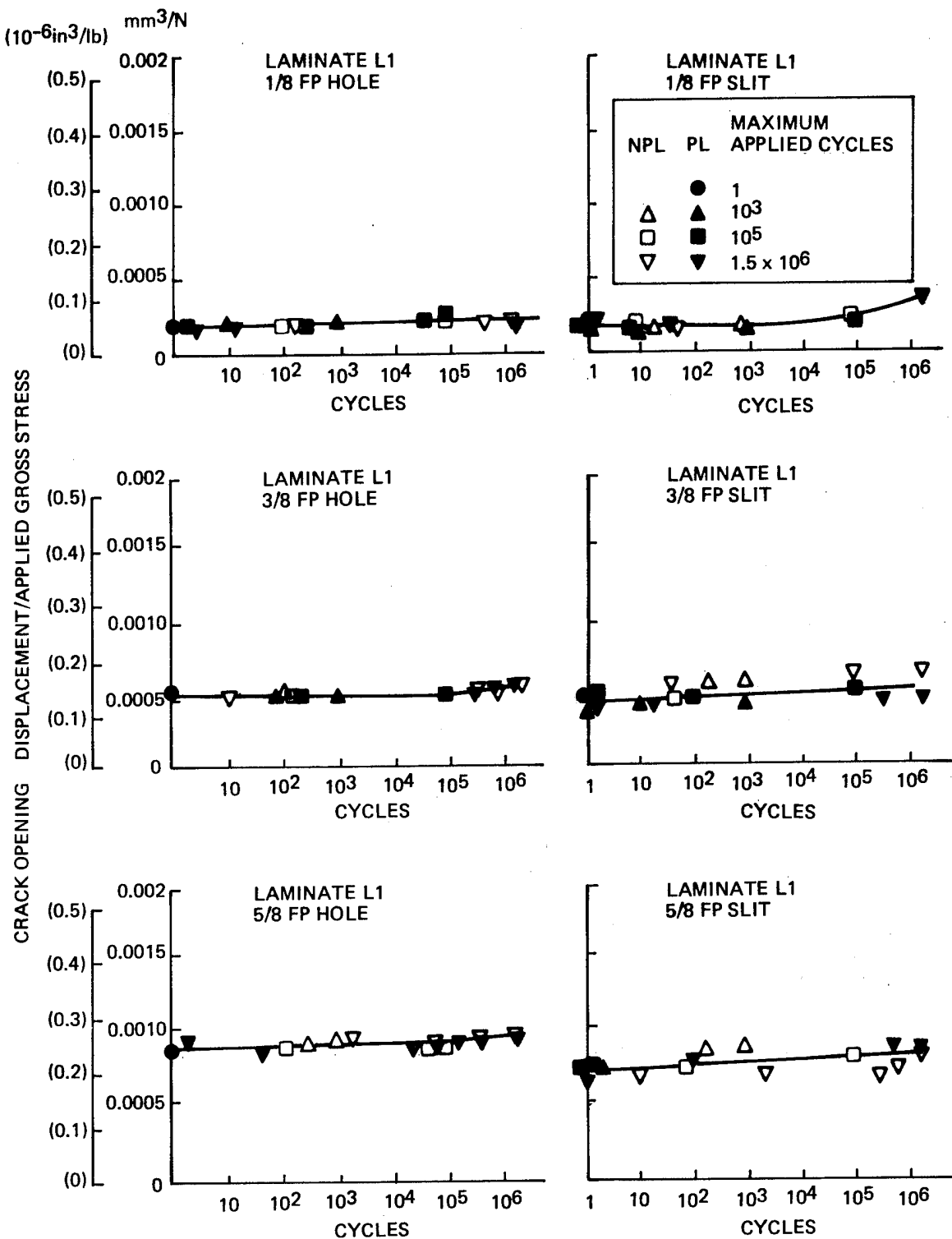


Figure D-1. Cyclic Load Crack Opening Displacement Result (Sheet 1 of 6)

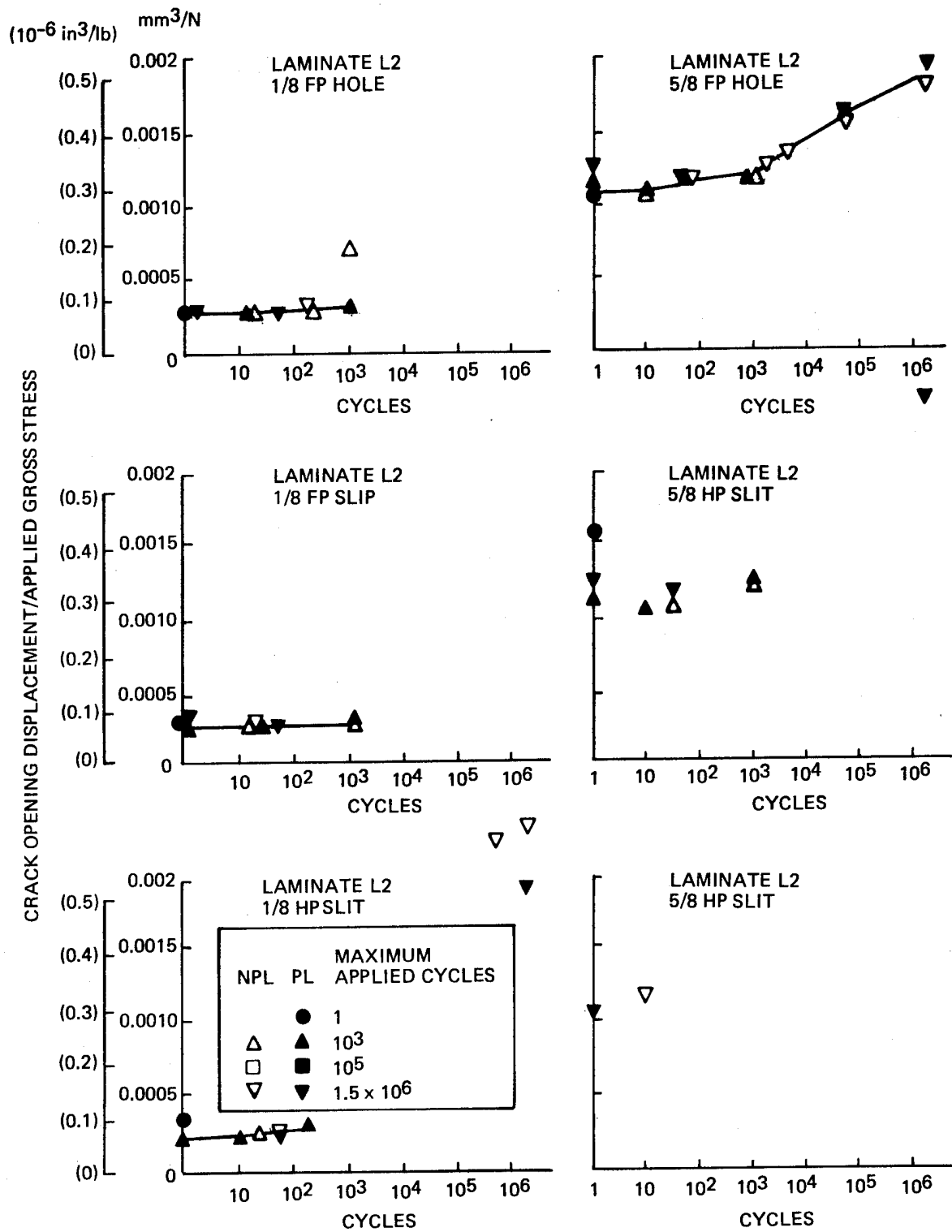


Figure D-1. Cyclic Load Crack Opening Displacement Result (Sheet 3 of 6)

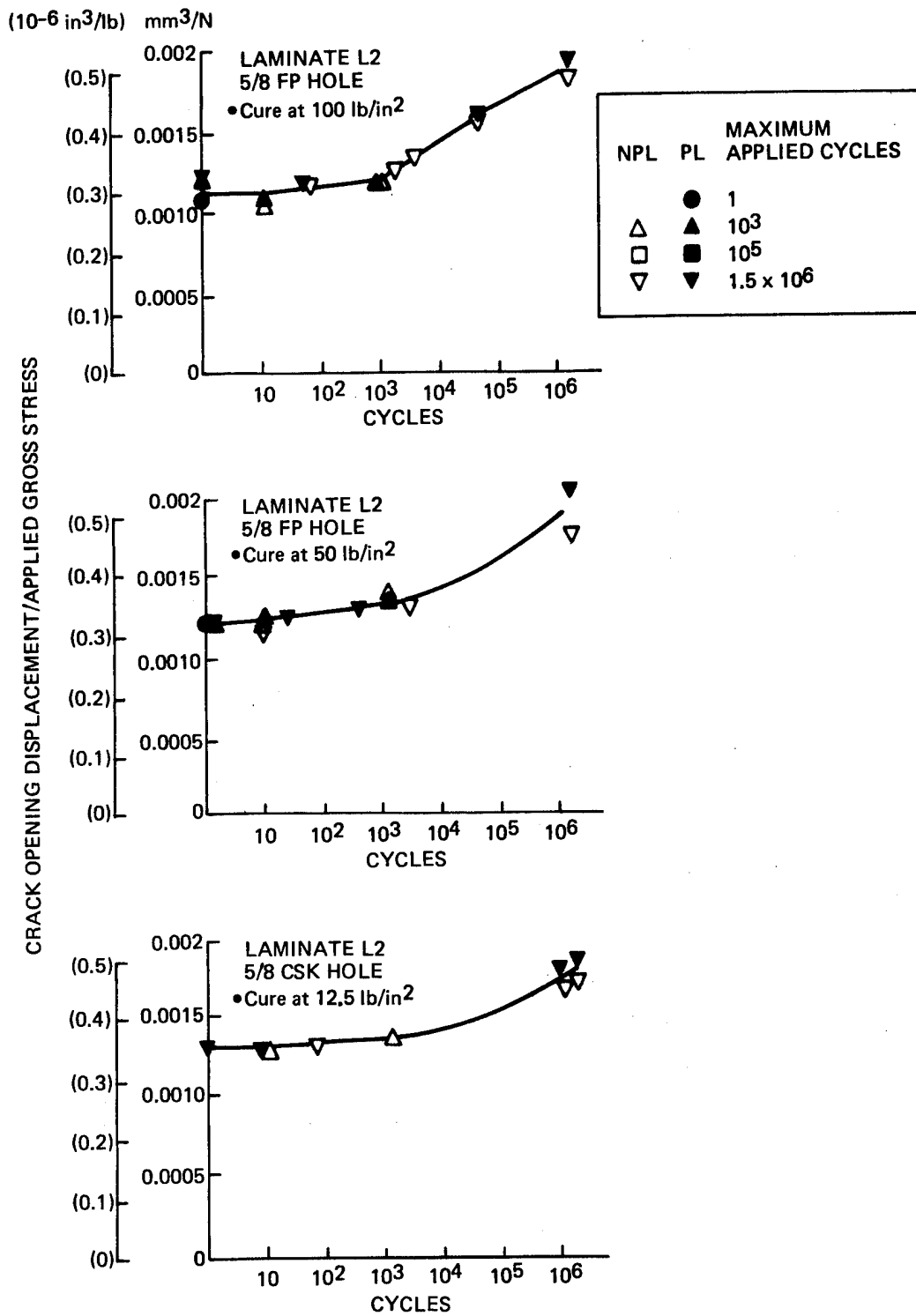


Figure D-1. Cyclic Load Crack Opening Displacement Result (Sheet 4 of 6)

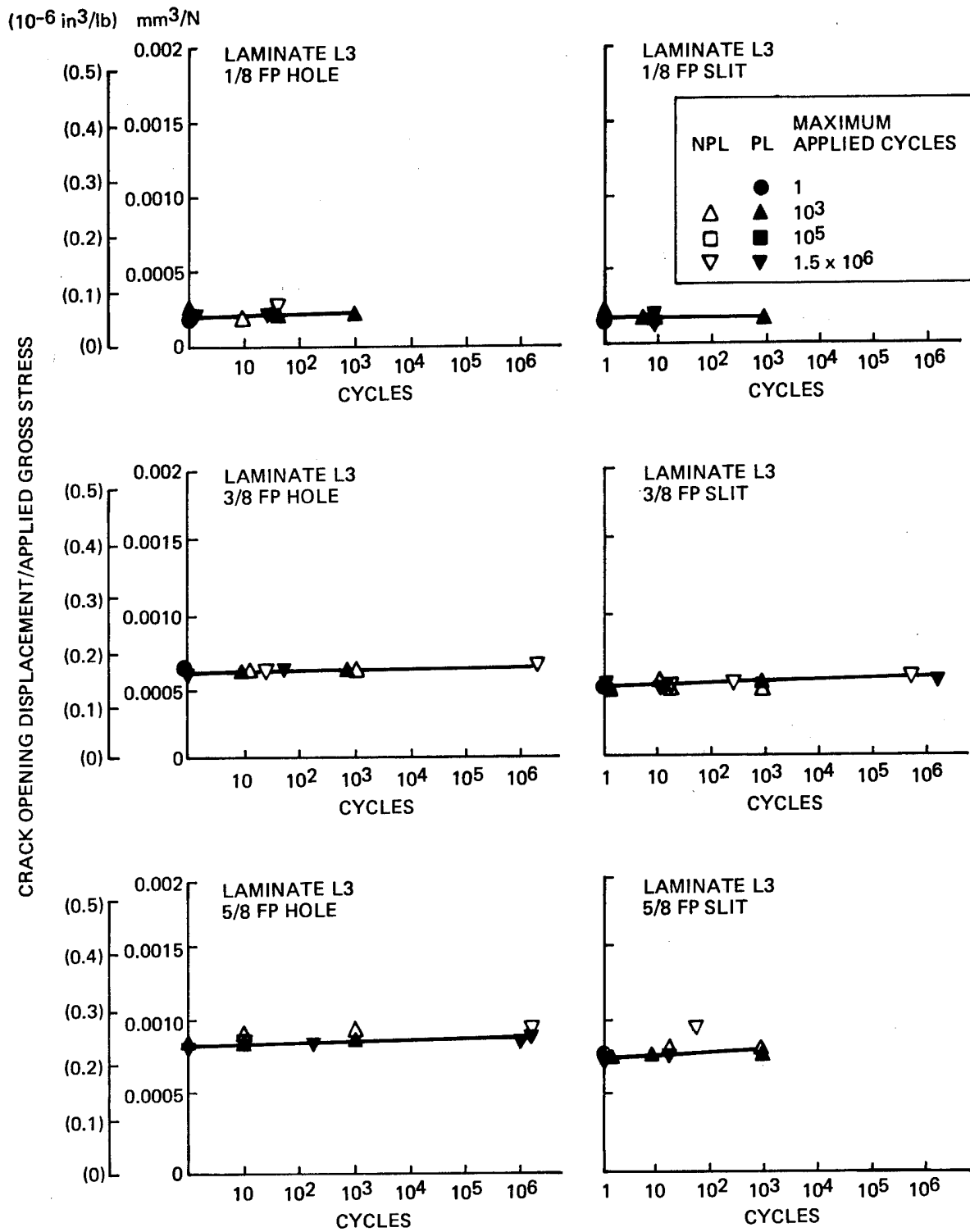


Figure D-1. Cyclic Load Crack Opening Displacement Result (Sheet 5 of 6)

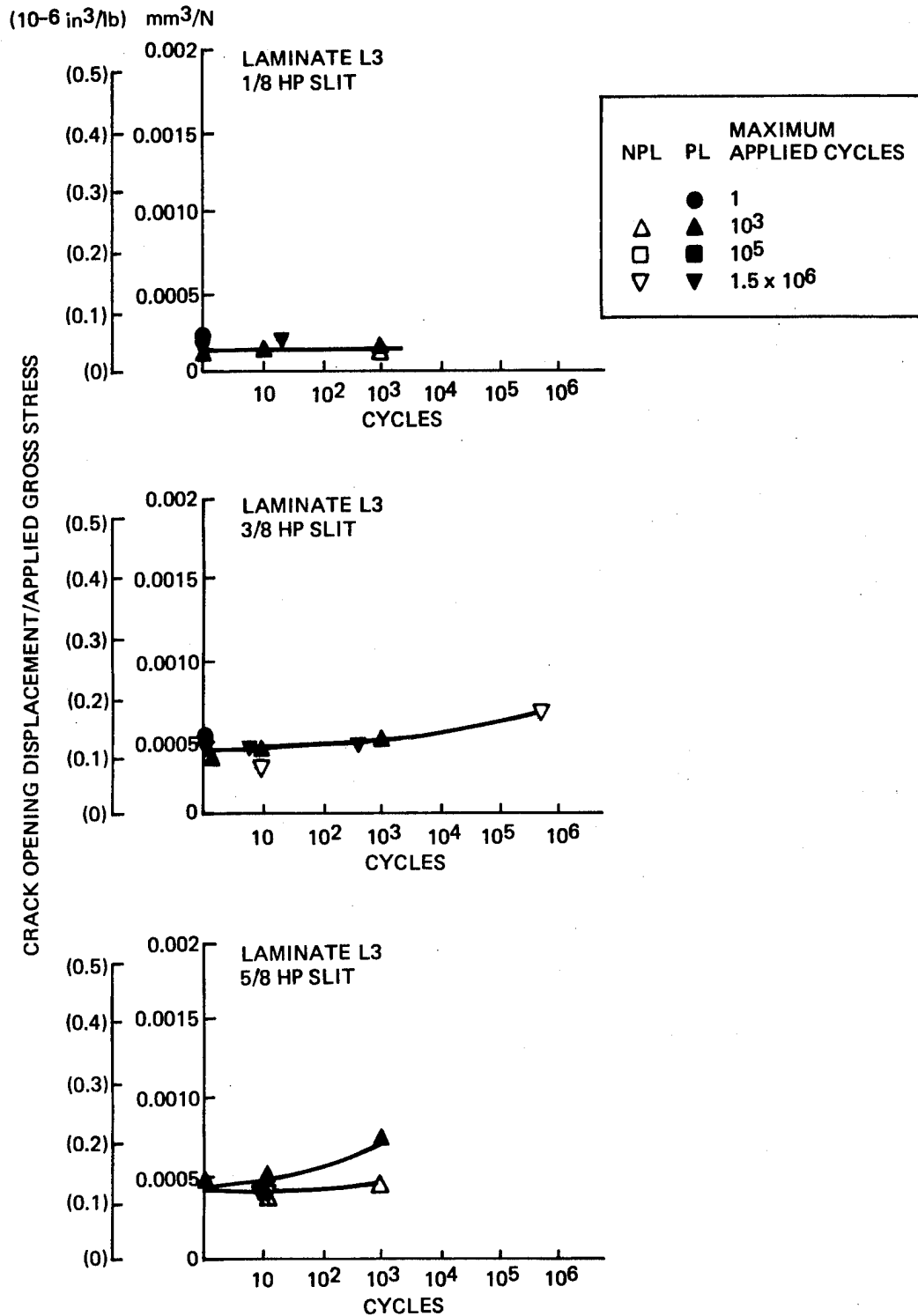


Figure D-1. Cyclic Load Crack Opening Displacement Result (Sheet 6 of 6)

APPENDIX E

PHOTOGRAPHS OF FAILED TEST SPECIMENS

This appendix contains photographs of typical test specimens after completion of the testing. One test specimen is included for each laminate configuration, defect type, and defect size. The specimens are identified by specimen number, defect code, and testing history.

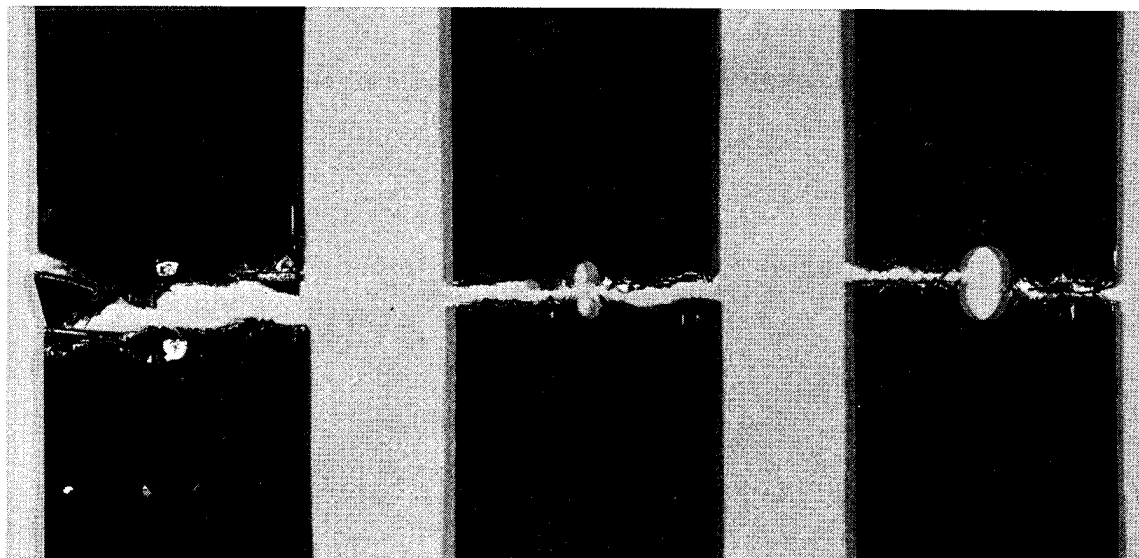


- Specimen L1-10-2
- Laminate L-1
- 10^3 cycles
- Residual static

- Specimen L2-1-2
- Laminate L2
- Preload
- Residual static

- Specimen L3-1-22
- Laminate L3
- 10^3 cycles
- Residual static

Figure E-1. Test Specimens With No Initial Defect

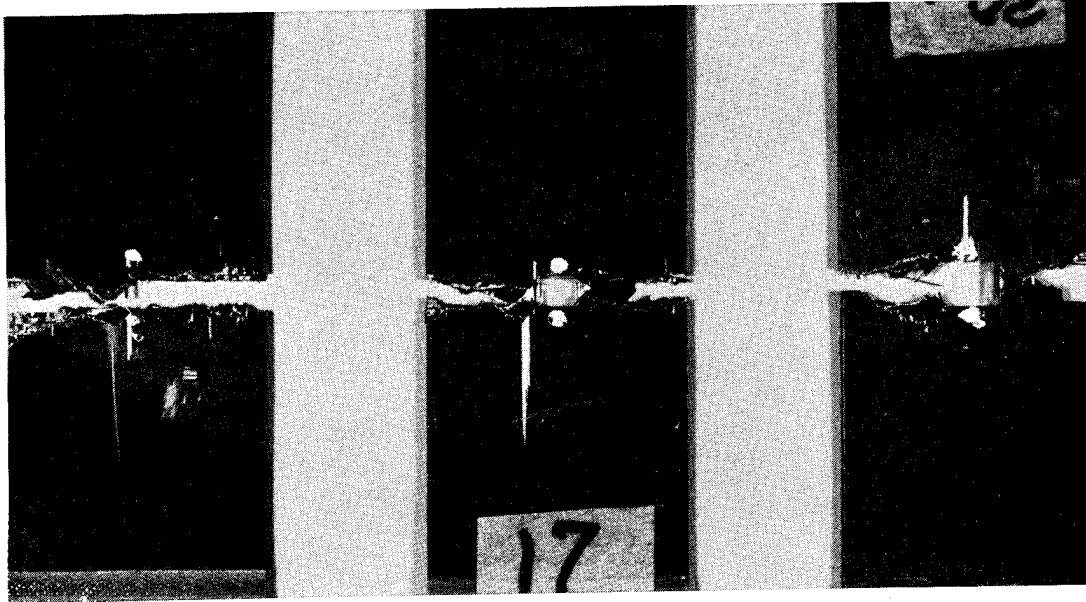


- Specimen L1-3-11
- 1/8 FP hole
- 1.5×10^6 cycles
- Residual static

- Specimen L1-1-7
- 3/8 FP hole
- Static

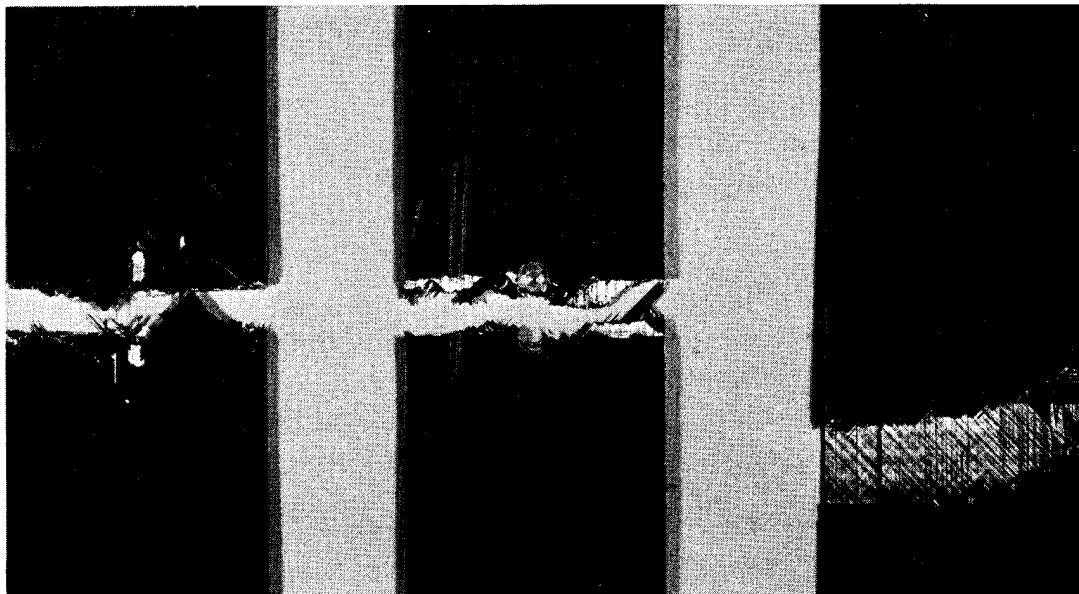
- Specimen L1-5-5
- 5/8 FP hole
- 10^5 cycles
- Residual static

Figure E-2. Laminate L1 Test Specimens Containing a Full-Penetration Hole



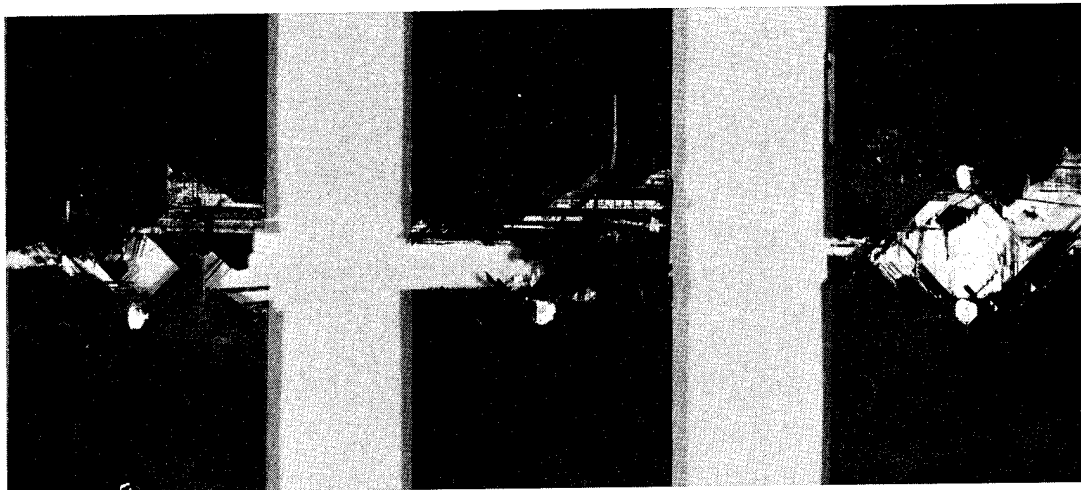
- | | | |
|-------------------|-------------------|----------------------------|
| • Specimen L1-6-5 | • Specimen L1-2-6 | • Specimen L1-7-14 |
| • 1/8 FP slit | • 3/8 FP slit | • 5/8 FP slit |
| • 10^5 cycles | • Preload | • 1.5×10^6 cycles |
| • Residual static | • Residual static | • Residual static |

Figure E-3. Laminate L1 Test Specimens Containing a Full-Penetration Slit



- | | | |
|-------------------|--------------------|--------------------|
| • Specimen L1-1-5 | • Specimen L1-1-10 | • Specimen L1-1-13 |
| • 1/8 HP hole | • 3/8 HP hole | • 5/8 HP hole |
| | • Preload | |
| • Static | • Residual static | • Static |

Figure E-4. Laminate L1 Test Specimens Containing a Half-Penetration Hole



- Specimen L1-2-3

- 1/8 HP slit

- Static

- Specimen L1-2-8

- 3/8 HP slit

- Preload

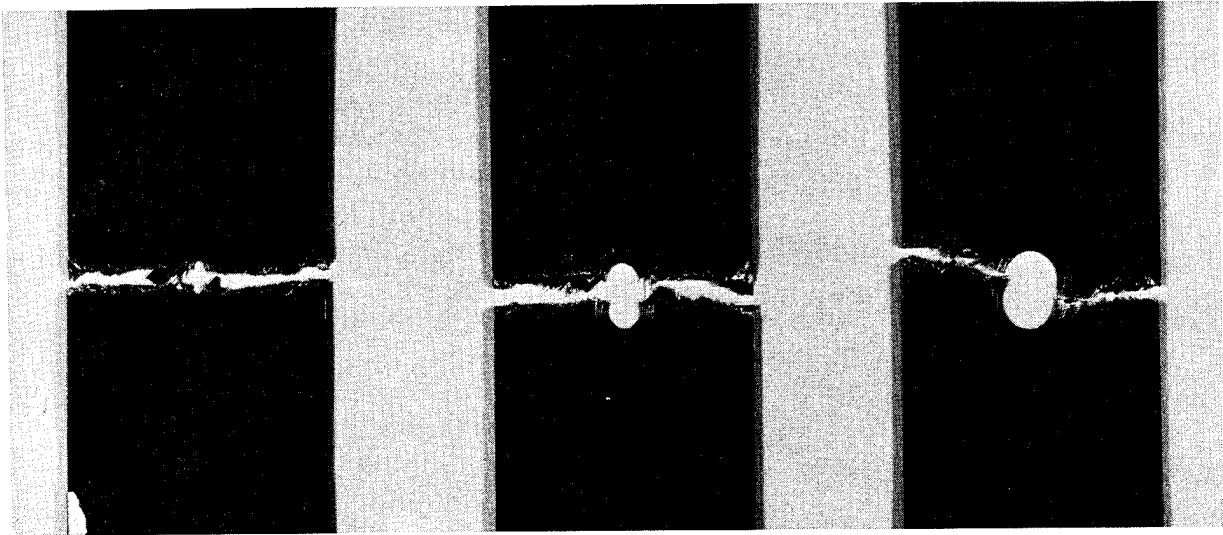
- Residual static

- Specimen L1-2-11

- 5/8 HP slit

- Static

Figure E-5. Laminate L1 Test Specimens Containing a Half-Penetration Slit

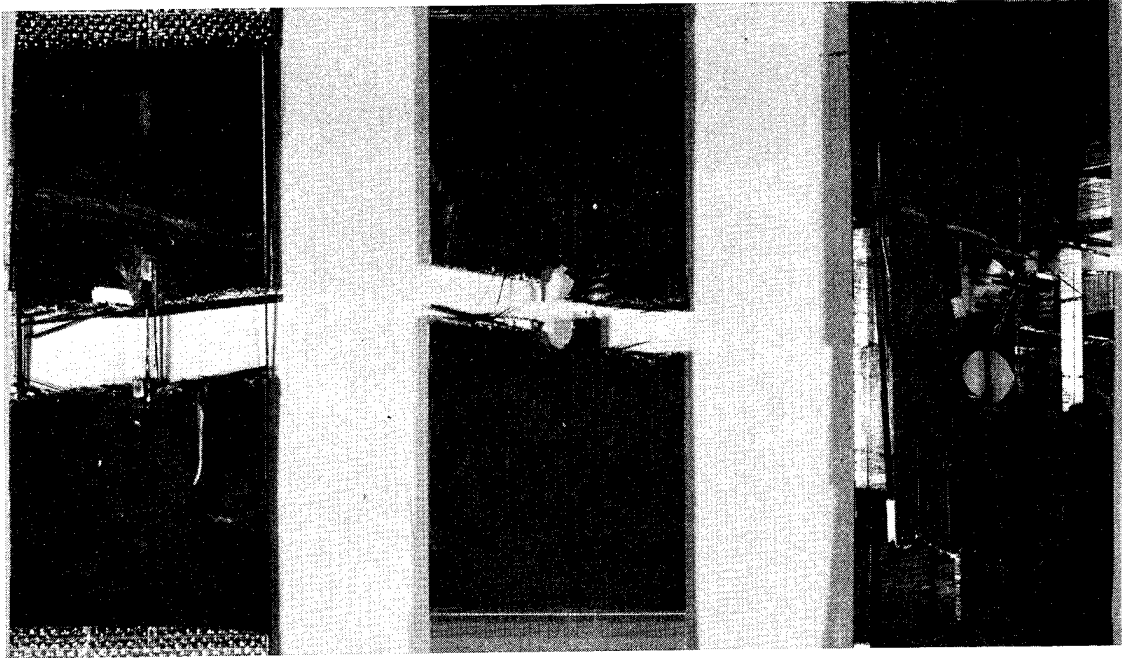


- Specimen L1-8-7
- 1/8 CSK hole
- 10^3 cycles
- Residual static

- Specimen L1-3-2
- 3/8 CSK hole
- Preload
- Residual static

- Specimen L1-8-12
- 5/8 CSK hole
- 1.5×10^6 cycles
- Residual static

Figure E-6. Laminate L1 Test Specimens Containing a Hole With a Full-Depth Countersink

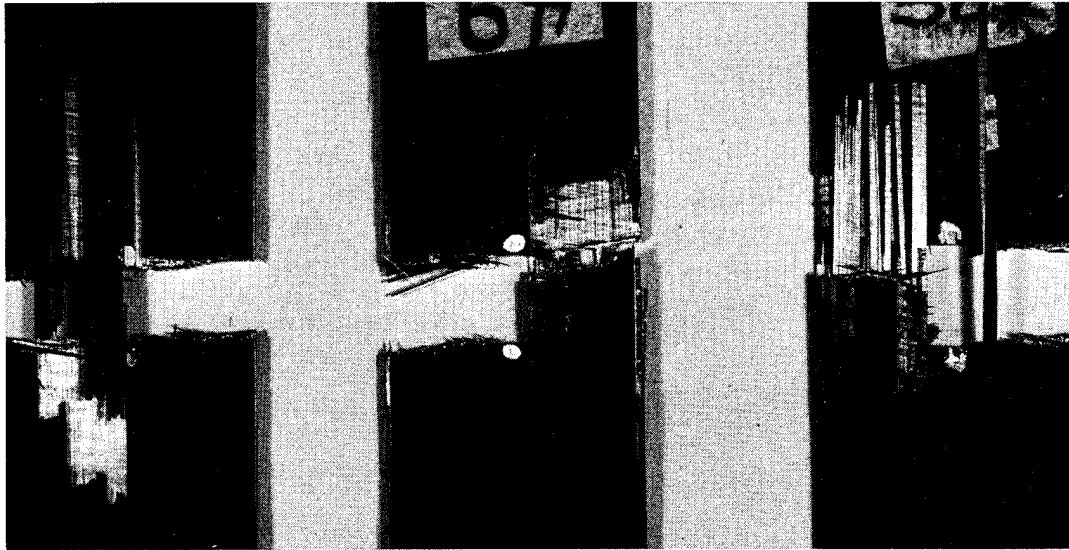


- Specimen L2-1-25
- 1/8 FP hole
- 1.5×10^6 cycles
- Residual static

- Specimen L2-1-6
- 3/8 FP hole
- Preload
- Residual static

- Specimen L2-1-29
- 5/8 FP hole
- 1.5×10^6 cycles
- Residual static

Figure E-7. Laminate L2 Test Specimens Containing a Full-Penetration Hole



- Specimen L2-1-10
- 1/8 FP slit
- Preload
- Residual static

- Specimen L2-1-14
- 3/8 FP slit
- Preload
- Residual static

- Specimen L2-1-42
- 5/8 FP slit
- 10^3 cycles
- Residual static

Figure E-8. Laminate L2 Test Specimens Containing a Full-Penetration Slit

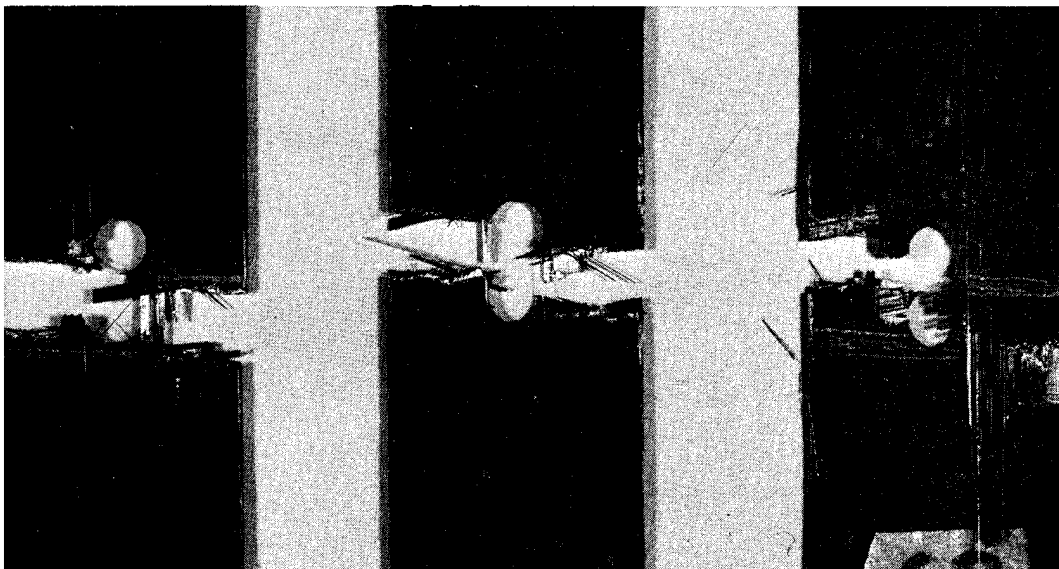


- Specimen L2-1-35
- 1/8 FP slit
- Preload
- 1.5×10^6 cycles
- Residual static

- Specimen L2-1-16
- 3/8 HP slit
- Preload
- Residual static

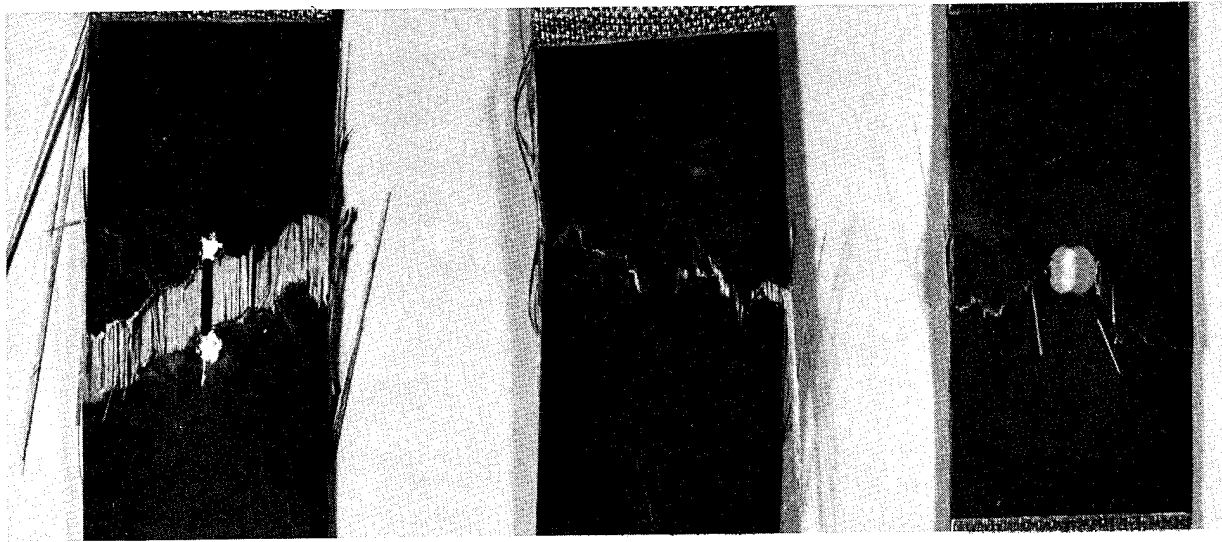
- Specimen L2-1-19
- 5/8 HP slit
- Static

Figure E-9. Laminate L2 Test Specimens Containing a Full- or Half-Penetration Slit



- | | | |
|---|--|---|
| • Specimen L2-2-3 | • Specimen L2-3-1 | • Specimen L2-4-2 |
| • 345 kPa/(50 lb/in ²) cure | • 172 kPa(25 lb/in ²) cure | • 86 kPa(12.5 lb/in ²) cure |
| • 1.5 x 10 ⁶ cycles | | |
| • Residual static | • Static | • Static |

Figure E-10. Laminate L2 Test Specimens Cured With Low Autoclave Pressure

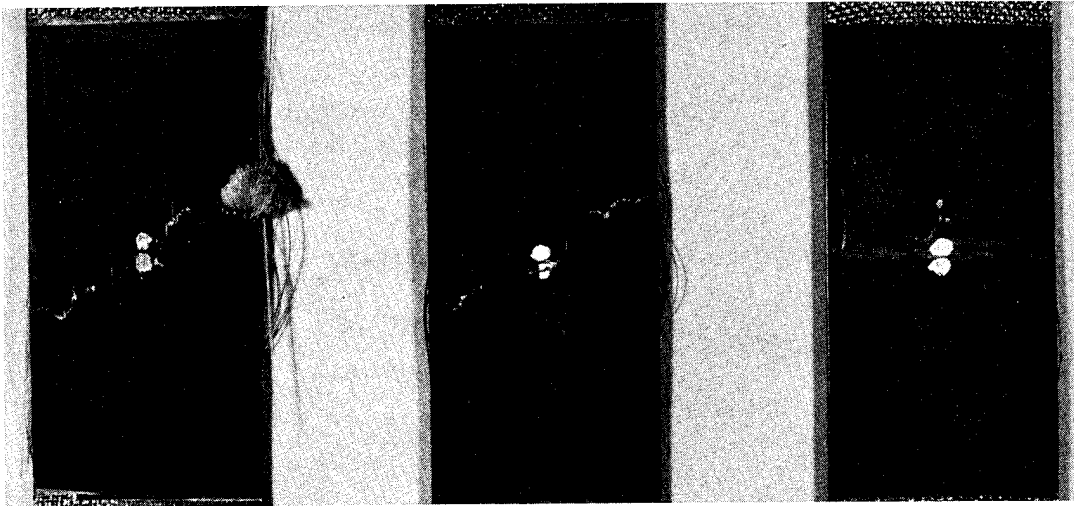


- Specimen L3-1-28
- 1/8 FP hole
- Preload
- 10^3 cycles
- Residual static

- Specimen L3-1-29
- 3/8 FP hole
- 1.5×10^6 cycles
- Residual static

- Specimen L3-1-7
- 5/8 FP hole
- Static

Figure E-11. Laminate L3 Test Specimens Containing a Full-Penetration Hole

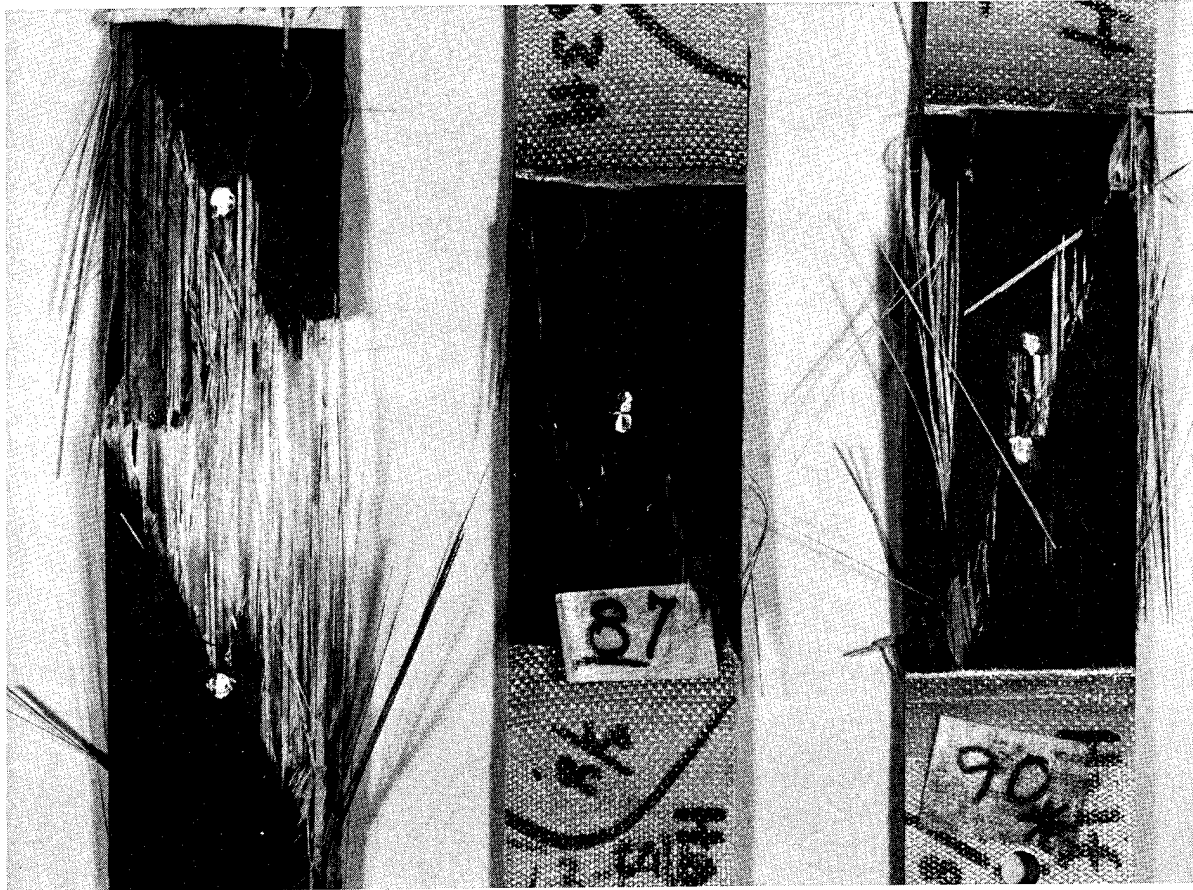


- Specimen L3-1-40
- 1/8 FP slit
- 10^3 cycles
- Residual static

- Specimen L3-1-14
- 3/8 FP slit
- Preload
- Residual static

- Specimen L3-1-17
- 5/8 FP slit
- Static

Figure E-12. Laminate L3 Test Specimens Containing a Full-Penetration Slit

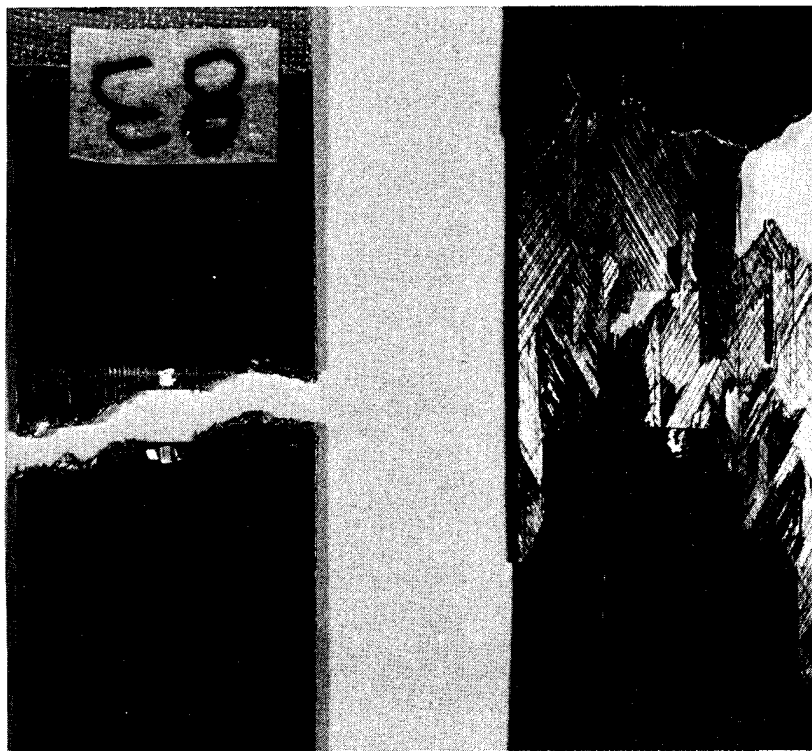


- Specimen L3-1-44
- 1/8 HP slit
- 10^3 cycles
- Residual static

- Specimen L3-1-15
- 3/8 HP slit
- Static

- Specimen L3-1-60
- 5/8 HP slit
- 10^3 cycles
- Residual static

Figure E-13. Laminate L3 Test Specimens Containing a Half-Penetration Slit



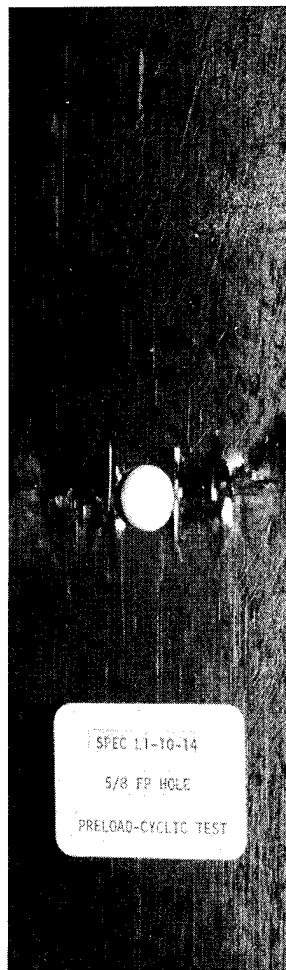
- Specimen L3-2-5
- 5/8 FP slit
- Preload
- Residual static

- Specimen L3-2-6
- 5/8 HP slit
- Static

Figure E-14. All-Graphite Laminate L3 Test Specimens Containing a Full- and a Half-Penetration Slit



- 7,300 cycles
- Fatigue Failure



- 22,800 cycles
- Fatigue failure



- 3,100 cycles
- Fatigue failure

Figure E-15. Tension-Compression Fatigue ($R = -1.0$) Laminate L1 Test Specimens Containing a Full- and a Half-Penetration Hole

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